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New England Water Works Association.

1927—1928.

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THE Association was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of 800 men. Its membership is divided into six classes, viz:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

A Life Member shall be a member whose service to the Association entitles him to special recognition by the Association.

A Junior shall be not less than eighteen years nor more than twenty-five years of age, a student or connected with water supply work.

An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

A Corporate Member shall be either a Water Board, Commission, Company or Municipal Corporation.

The initiation fees and annual dues are as follows:

	Initiation Fees		*Annual Dues*
Members	$ 3.00	Members	$ 6.00
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Associates	10.00	Associates	20.00
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This Association has six regular meetings each year, all of which, except the annual convention in September, are held at Boston.

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*Deceased.

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New England Water Works Association

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This Association, as a body, is not responsible for the statements or opinions of any of its members.

REMINISCENCES OF A SUPERINTENDENT.

BY DAVID A. HEFFERNAN.*

[*Read September 14, 1927.*]

A few weeks ago, after having been notified of my appointment to a committee of this Association which was to study the growing popularity of the merging of municipal departments, I sat at home smoking, and my thoughts took a meditative slant.

I thought of my first connection with the Milton Water Works thirty-seven years ago. At the time, I was just coming into manhood and the water works was just getting started. It purchased its water from a neighboring company and distributed it. Later, in 1902, the town purchased the plant, entered the Metropolitan System and incidentally I was made superintendent and am still on the same job.

I thought of the superintendent of twenty-five years ago and today. I wondered what might become of him in the next twenty-five years, wondered if he would become extinct, relegated to the background by the movement to supplant the practical superintendent by the theoretical engineer. I thought of the progress that I had seen and made the inevitable comparison between means, methods and appliances of now and years ago.

Think of how far apart gates were placed in main lines years ago! How many hydrant branches were gated? Hydrants were set farther apart than they are now. Lead was the only jointing material in use. Today a real saving in the cost of pipe laying may be realized by the use of lead substitutes.

As an example of what can be done with these substitutes I want to tell of an experience I had a couple of weeks ago. We had just finished a line in a new development, and two days after its completion a truck backed into one of the hydrants. It developed that the entire hydrant branch, 13 ft. long, including a gate, had been twisted in the tee about 10 degrees. A jack was placed at the side of the hydrant, pushing it into an upright position. The water was turned on all the time, and the joint did not leak a drop before, during or after the shift. The joints had been run with leadite.

We have used deLavaud pipe with cement lining exclusively the last

*Superintendent, Water Department, Milton, Mass.

two years. Our reasons for installing this pipe are many. It is cheaper, easier to transport and handle, and entirely satisfactory in use. And, perhaps most important of all its good points is its lining of cement which will prevent formation of tubercles on the pipe inside and the resulting reduction of its waterway. I do wish, however, that it were possible to make it with a bead on the spigot end. We have had only one break in 6½ miles. This was in 10-in. pipe under 115 lb. pressure which had been in service for one year. If this pipe is properly handled and installed, my opinion is that it will prove quite satisfactory.

Our town is of fair size, having a population of about 15 000 and 69 miles of main pipe, but we have been as progressive as was deemed consistent with judicious conservatism. Some years ago we equipped the department with a Darley pipe locator. This has proved itself of inestimable value, and I cannot conceive of even the smallest water works being without one. Record plans may be quite complete, but buildings are continually being altered or removed, and other changes being made constantly render obsolete parts of the plans, making the pipe locator a very important piece of water-works equipment.

Later on we purchased, at different times, several instruments for finding leaks. The one we now use and which has given best results is the Geophone. I believe that the first time we used it, it paid for itself.

Another item of small equipment is a set of gages including a flow gage and perhaps two or three ordinary pocket test gages fitted for attaching to hydrant nozzles. Proper use of these little instruments will give a good idea of just what condition the pipe is in, will tell you if you have a closed gate in the line and will show just how much improvement a new cross-feeder or a larger pipe replacement has made.

Four years ago we mounted an I-R air compressor on a 1916 2-cylinder Autocar chassis which, up to that time, had been used as a truck and equipped it with paving breaker, jackhammer and clay digger. Heretofore, our drilling had been done by hand; a slow, tedious, expensive job. The new type of tar road, as well as asphalt or paved roads, make such a machine an important adjunct to the equipment of water departments. I would not attempt to tell how much money this equipment has saved us, but I do know that we simply could not get along without it.

This year we purchased a Keystone excavator, broke in one of our own men to operate it and have used it almost continuously since May 1. The machine is operated by a 60-h.p. gasoline motor which is ample. Crawlers on the front end make for better traction. It is equipped with a 24-in. drop bottom ditcher, a ¾-yd. skimmer scoop and a backfilling blade for use on the ditcher. Backfilling may be done either with the blade attached to the ditcher or by the skimmer. By use of either of these the material may be either pulled or pushed into the trench, depending upon which is the more convenient.

We have an agreement with the Highway Department by which they

may use the machine when we do not need it, and it has proved very successful in removing the old surface from streets and placing it in trucks for dumping. For use of this machine we charge town departments $35 a day which figure we estimate includes wages, maintenance and depreciation. As a steam shovel costs $50 to $60 per day and is not able to do the clean job of grading that the skimmer does, the Highway Department gains just so much, as well as benefiting our department by keeping the machine busy when we have no use for it. We have not had the machine long enough to gather worthwhile figures on the cost of its operation but feel quite sure that it saves at least half the cost of trenching and rough backfilling.

I mention these pieces of equipment because they stick out in my mind as having a great value to water works no larger than ours, and I feel certain that they would prove their worth in other towns as they have in Milton.

So much for equipment.

I remember how proud I was when I became a member of the Association in 1902. As you all know, the Association was formed with the intention of bringing superintendents together so that all might benefit from an interchange of ideas. Some years later our engineer brethren were invited to join and, by the way, have been so progressive of late that they have scared the more retiring superintendents into seats in the rear of the hall. In passing, let me say that modesty is a virtue, and those practicing it will be rewarded in the next world, but none of your salary is paid you for your modesty. If you keep on being retiring, that is just what you will be asked to do by your superior.

You know they could hold a religious gathering out at Braves Field and you as an outsider might know that something was going on there but would not know what it was. On nights when a fireworks display is held, however, if you live within 10 miles nobody has to tell you what is in progress. It is the same way in this Association. Outside of Pat Gear and a very few other superintendents, who do the most talking, the superintendents or the engineers? You win, the engineers do. Of course, someone has to talk and they are willing to do the job.

When an engineer has a technical paper with a lot of dry figures that mean something only to an engineer, you superintendents begin to squirm around in your chairs and speculate on how much longer he will talk or wonder if you can make the door without everyone looking at you.

But when a superintendent talks. Oh! then it's a grand and glorious feeling. Why? Because he makes grammatical errors, gets red in the face, says things that you know are not so because your experiences have been to the contrary, and you just ache for him to stop talking so you can tell him what you think. Then when he does stop and you are ready to get on your feet, you hesitate a second longer and wonder if anyone will notice the trembling in your hands or the quiver in your voice when you get up to talk and, for fear someone will, you sit back in your chair and say to yourself, "Let someone else tell him!"

And the result? You can see it coming. The engineers present most of the papers, and people get to know there is such a person and forget the superintendent. Then they begin to talk about merging departments with an engineer in charge, the superintendent losing his identity in the rank of general foreman.

Some of my best friends are engineers and I hope they will not think that in this harangue I am trying to belittle them or their work. I know they have done a lot for me and other superintendents but I am trying to wake up my fellow-superintendents, and I am sure my engineer friends will take what I have said in the spirit in which I mean it.

In modern practice we superintendents would be all at sea if we were without the invaluable advice of engineers, but superintendents have the practical end of the work to perform, and I want them to realize their duties and abilities. If they advertise themselves it will help them. Let them read a paper here at the meetings and then go home and tell the editor of their local paper about it. He will be glad to publish an item about it, because it will be news, believe me. I think you will all agree that it would be front page news in the local paper if some superintendents said what they thought at these meetings.

In conclusion, let me say: "Be progressive, supply your department with modern equipment and then let the citizens of your town know what you are doing!"

DISTRIBUTION SYSTEM MAINTENANCE.

A Report of the Proceedings of the Superintendents' Conference of September 14, 1927.

STEPHEN H. TAYLOR,* Chairman.

Street Location of Mains.

GEORGE A. KING.† The building of cement roads has created a demand that water mains be laid in such a way that it shall not be necessary to cross under cement roads with services. The main street in Taunton is about 70 ft. wide. When it was decided to reconstruct it as a cement road, I put a 4-in. main on one side of the street opposite the existing 16-in. main, in order that all the services on this side might be taken from the 4-in. main. There will be no fire protection from the small main, although it is connected at each street intersection, with the 16-in. conduit.

THE CHAIRMAN. At New Bedford, one or two of our wide streets have mains on both sides of the street. In some cases this is because the street is quite wide and it seemed better economy to have short services and at the same time to have the mains away from the street pavement. In these cases the sidewalk is constructed as a flag or concrete walk with a space between the walk and the curb for grass and trees. This space can quite readily be dug up for services and seems to constitute a good place for our mains.

In another street a very large trunk sewer, 6 ft. in diameter, is located in the middle of the street. The sewer is so near the surface that it would not be safe to pass over it every time we wish a service on the other side of the street; it is too deep to go under it economically. This seems to be another case where one is justified in putting two mains in a street.

HENRY T. GIDLEY.‡ Should one put both mains in so that they will care for fire protection, or only for domestic supply?

THE CHAIRMAN. In one case we put a 12-in. main on one side, and a 6-in. service main on the other. I think one large main is enough.

DAVID A. HEFFERNAN.§ Has anyone placed two fire lines in a street 70 ft. wide or wider?

SAMUEL A. AGNEW.° I have a 20-in. line in Hingham on one side of the street and a 12-in. on the other, thus leaving no uncertainty.

THE CHAIRMAN. I think it has been figured out that it is cheaper to lay a second line and shorten up the services than it is to lay one line and as a result have very long services on one side of the street.

*Superintendent of Water Works, New Bedford, Mass.
†Superintendent of Water Works, Taunton, Mass.
‡Superintendent, Fairhaven Water Co., Fairhaven, Mass.
§Superintendent, Milton Water Works, Milton, Mass.
°Superintendent, Hingham Water Works, Hingham, Mass.

W. S. Cramer.* When the main is laid under the sidewalk is it not as objectionable to tear up the sidewalk as the street?

Frank J. Gifford.† No. There is commonly no permanent pavement on the sidewalk; it is usually a gravel walk.

The Chairman. At New Bedford, the walk, in one case, is only about 4 ft. wide, and there is a grass plot on either side. Of course one can tunnel under the walk for services and the grass plots can be replanted.

A. P. Murray. Does not the owner have something to say about the sidewalk?

The Chairman. I think not, — if the city decides to lay the pipe in the sidewalk.

A. P. Murray. Does the city take care of the street from property line to property line?

The Chairman. Yes.

A. P. Murray. We do not. We only lay the sidewalk.

Mr. MacKenzie. If water-works men have any influence with the town officials — possibly some of us do not have much — and improvements on wide streets that have permanent pavements are to be made, it might be well to get the authorities to lay them so that the grass plot, which is now left in a great many streets between the edge of the pavement and the walk, would be left open and trees planted back of the walk. It would simplify our problem greatly.

W. S. Cramer. In view of the difficulty I have experienced in maintaining flow through mains on both sides of the street, I believe that in the future I shall use a 2-in. precalked pipe, and run it from one main across the street in front of one lot to take care of the two adjacent lots. I believe this would serve better than a second main. Another alternative is to go to the expense of making both mains the same size, laying two 6-in. pipes instead of a 4-in. and a 6-in.

The Chairman. Is this a fair statement to make as a summary of this discussion: that in any streets with permanent pavements — or even if they are not permanent — of over 60 ft. in width, there should be two mains?

Samuel Agnew. It seems to me it would depend somewhat on the character of the buildings along the street. For instance, at Hingham there are many places where it would not pay us to lay two mains simply because the estates are quite large, and it would be only here and there where we would have to cross with a service pipe. On the other hand, there are certain sections where it would be a matter of economy to lay two pipes, one on each side of the street, because of the number of houses there are. It would seem to be a matter of political economy, to be determined entirely by the number of houses which are likely to be built on either side of the street.

---

*Superintendent of Water Works, Lexington, Ky.
†Superintendent, Water Company, Dedham, Mass.

FRANK J. GIFFORD. I think the question should be: What is the minimum width of the street on which it is economy to lay parallel mains?

H. M. KING.* Aren't you running into the question there of whether the consumer pays for the service or the city pays for it? In Springfield the consumer pays for the service. He pays for labor and materials. We have always gone upon the principle of laying the main 18 ft. from the eastern and northern lines of the street on a 50-ft. street. In a 60-ft. street we lay 7 ft. from the center of the street, which is the same proportion as on a 50-ft. street. We have several streets which are very wide, and 4-in. mains have been laid on both sides of the street to take care of the services. At intersecting streets the main has been connected to these house services which go down the various streets. That answers the purpose very well until property changes in character, the houses are taken down and apartments are built. Then the Fire Department wants hydrants for which 4-in. pipes are no good.

Then, too, one runs up against the sale of properties. We have one case where a real-estate developer, had a considerable number of 50-ft. lots, and before they put in the permanent pavement he wanted a service laid to each one of those lots. He was influential enough to have them put there and they stayed there 10 to 12 years before they were called into service. In the meantime the plans were changed and the property was cut into 60-ft. lots. Now the houses that are built all want flushometers. The services, however, are all 1-in. and are not sufficient in size to take care of flushometers. Nearly each one of the services, therefore, has been replaced by a larger service.

H. V. MACKSEY. When you consider whether you will put in one or two mains on a street, isn't it well to consider that you are not the only pebble on the beach? If you do not want services to run across the street, you must have two water mains. Along comes the Gas Company, and what is easiest for water is easiest for gas, and you have two gas pipes, which is four pipes in all. Then you should have a drainage line on each side of the road, and you are liable to have about six or more lines down the street. Up in the country they don't care whether you put them across or not. But if you are going to prevent crossing the street, you must remember that you must provide for about six lines down the street if everybody has got to double up.

THE CHAIRMAN. I do not think that we should pass any vote on this question of laying two mains on wide streets. I think it is so controlled by local conditions that there is no need to do so.

PROVIDING SERVICE LINES TO VACANT LOTS.

J. E. GIBSON.† I think the practice of putting in services in advance of building is a waste of time and money. We have done a little of it in Charleston and we still carry the expense on our books.

*Superintendent, Water Department, Springfield, Mass.
†Engineer; Commissioners of Public Works, Charleston, S. C.

Some six or eight months ago,— after the last mayoralty election,— we had a campaign for improving the streets. Everyone seems to think — and I agree — that it is a nice thing to be able to roll smoothly on rubber. In days past, with old Dobbin and the buggy, we used to like the "thank you marms." Now we don't like them. The Mayor and Council decided that they would not let any more streets be opened and immediately ordered the Commissioner of Public Works, who has charge of the Water Department, to lay services to every vacant lot. Some lots are 60, some 40, some 30 ft. We immediately passed the buck by saying, "What is a lot?" We put it up to the city engineer to define what a lot was. He said that he did not know and that he would not take any stand on it. Well, I said that I would not either. They paved a number of streets after we had put in our mains. Of course the street pavement does improve the looks of the street, and somebody then wants to build right away. One or two builders came in and wanted to cut up the asphalt pavement to make service connections. I asked for a permit from the Public Service Department, which has charge of the streets, and they said "nothing doing." I had to inform the applicant that he would have to wait. He said, "How long do you have to wait?" I said, "God only knows." "Well," said he, "I shall see my lawyer." The next day I got a permit.

The result was that I got a dressing down from the Mayor, but replied, "Well, Mr. Mayor, I asked for this permit." He said, "You knew the ordinance was in existence?" I said, "Yes." "Why didn't you put the service in?" I said, "I didn't know the man; I didn't know he owned the property there; I had no way of finding out." "Did you try?" "No, I didn't try." "Well," he said, "you are not going to cut up any more of these pavements." I said, "All right, Sir, that is perfectly agreeable; I don't care whether the town grows or not." "What do you mean?" "Well," I said, "I think when you see a street being cut up and buildings going up on the property, that the town is growing, that the city is getting more taxes; that instead of getting taxes on a vacant lot valued at $200 or $300 an acre, you are probably getting taxes on a house valued at $5 000 or $10 000; it is a sign of progress." And I added, "Further, Mr. Mayor, you are too good a lawyer to know that you can deny a man the right to water, because you have put down a new pavement. That man paid for that pavement in front of his house under our frontage assessment, and you know that you can't stop him." "Well," he said, "we can make a good bluff." I said, "I don't believe in bluffing." To make a long story short, we are now getting right into another new mayoralty campaign, and anyone can get a service permit now without any trouble at all.

As to State highways, we have thus far, been able to work pleasantly with the State. One or two Federal-aid jobs had to go through a lot of red tape, but after having complied with the red tape, we had no difficulty. The process up to date has been that we must either replace the pavement in as good condition as we found it, or permit them to do it while we pay

the bill. Needless to say, I have "passed the buck" there and let them do it. I would rather pay their bill and let them assume the responsibility, than to have them come back and say I did not do the job right and have to do it over again. That has worked out nicely.

I have laid duplicate mains on as narrow a street as 40 ft., because the conditions were such, with trolley tracks, tile drains in the center of the street, two sewers on each side, telephone conduits, and gas mains, that I figured it would be better to lay duplicate mains on opposite sides of the street in the boulevard or grass plot, and that I would have a cheaper proposition than to try to tap and bore through under that pavement or cut it open. This has worked very nicely in several instances.

I do think that you are taking a great chance when you go ahead and try to anticipate your needs, with the rapid changes which are taking place. You might lay your services now for bungalow houses on 50-ft. streets, and next year the entire complexion of that community might change and you would have brick buildings, much more pretentious, with flushometers, as has been mentioned, and instead of having one bathroom in the house you might have a half dozen. That is the way it goes. I think it is best to cross the bridge as you come to it, rather than trying to anticipate future requirements.

A. R. HATHAWAY.* I want to supplement Mr. King's remarks on the Springfield situation — not that they need strengthening in any way, but my memory can go back farther than his. I remember the time when the first brick pavement was laid in the street and we put in taps and services to the curb as every lot was laid out at that time. Those were carried among our assets. Only a small percentage of these taps was ever used.

When the first asphalt street was paved in Springfield we laid services in the same way and carried them as an asset. When the owner put up a building on the lot and wanted water, we forced him, as far as we could, to use one of those services and pay for it. Then I credited the account and charged it to the consumer. But, as I have said, very few were used. People who bought lots would buy two or three lots and then build brick blocks.

We have also had, in Springfield, the matter of laying down a rule regarding the opening of permanent pavements. One of our mayors some time ago got out a notice that after the street was paved it would not be opened for five years. I understood afterwards that it almost came to court action, but it was found to be a fact, and the judge so announced, that you could put up your signs, but if a taxpayer built a house and wanted an extension you could not refuse him.

THE CHAIRMAN. I am personally very much against the idea of providing services in advance. We have laid a few in New Bedford, and I don't think that one-tenth of them have ever been used. They are always in the

*Water Registrar, Springfield, Mass.

wrong place, or they are the wrong size, or something. It doesn't seem to me at all practical.

GEORGE F. MERRILL.* In regard to opening the State highways, — I have never had any difficulty in obtaining permits. The permits are made out in the name of the municipality. In the western part of the State, division engineers now grant a permit and send it back inside of 24 hours, where several years ago it might take two weeks. I have noticed that if the location plans are examined to give the proper stationing of the place where pipe is to be laid, you will get a good deal quicker action.

F. J. GIFFORD. I think the testimony here is to the effect that it is unreasonable, and impractical to lay services in advance. I have personally made up my mind on laying services to vacant lots, or, as Mr. Gibson said, I should like to have somebody define what a lot is.

THE CHAIRMAN. Could we come to a decision, or express an opinion regarding the practice of providing service lines to vacant lots?

(On motion, duly seconded, it was VOTED that "It is the sense of this meeting that the laying of service lines to vacant lots is impractical and should be discouraged.")

FLUSHING MAINS.

THE CHAIRMAN. In New Bedford we flush mains regularly in the spring and fall. The work is done in the daytime. In some places I believe that day flushing reduces the pressure or inconveniences the takers so that flushing is done at night instead. We flush dead ends more frequently than twice a year, whenever they seem to need it, or whenever we get a complaint. I don't know whether that is the general practice or not.

DAVID A. HEFFERNAN. We flush twice a year. We make what we call a thorough flushing at night. When ordinary complaints of dirty water come in, we may flush during the daytime. Of course, we do not open the hydrant enough at those times to stir the water up too much.

PERCY R. SANDERS.† There is just one objection that I can see to flushing at night. It is difficult to tell at night when the water is running clear and it is time to shut off the hydrant. For this reason we flush during the day.

THE CHAIRMAN. Isn't there also an economic question? Do you have to pay your men double time for night work?

DAVID A. HEFFERNAN. We do not. The men do not work the next day.

A MEMBER. I have seen some flushing that I think simply stirred up the water. I shall, therefore, give our practice. We advertise ahead in the papers that at a certain time the mains are to be flushed, and that the pressure will, therefore, be low. Starting at the reservoirs we operate our blowoffs until we get into town. This operation takes until about half-past

*Ware, Mass
†Superintendent of Water Works, Concord, N. H.

four in the afternoon. Then we stop until half-past seven. At that time we open the blowoffs into the river for about an hour — usually it takes from 40 minutes to an hour to run the water clear. Next we proceed along each main line and run through to the last blowoffs of any size on the branches, with the idea of running the dirty water right through to the end of the main if it is possible. If we have time, up to one o'clock at night, we open the hydrants on the branches just enough to blow the dirty water out of the hydrant branch, because we depend on the blowoffs at the end of the main to carry the dirty water through. Since we have used this system, we find that when we go to the office next morning people no longer call up as much as in the past to know why the water is so dirty. Of course, they know in advance that the work is going to be done. We flush twice a year. Once in a while, in a bad season, we have to flush in midsummer, but that is unusual.

THE CHAIRMAN. Our practice is somewhat similar. We start at the reservoir and get our big mains clear down to our gridiron. We have a gridiron about five or six miles long and a mile wide. We take each section, after we get down into the gridiron, and let the water come in first from one direction, then from another and finally from a third, until it has been in from all directions and the section is thoroughly cleaned. It is our practice to flush in the spring and fall, so as to be sure that our hydrants are in good condition for the winter. We practically operate every gate and hydrant in each flushing operation. It is also a check on the condition of our gates and hydrants. We have had no difficulty in doing it in the daytime.

HENRY T. GIDLEY. We find that if we open a hydrant very quickly and very suddenly it will roil up the water in the main, but if we open it up more slowly it lets the worst water in the lateral drain out first. We gradually open the hydrant more and more until the water is clear. We have no trouble in flushing during the daytime if we proceed carefully.

GEORGE F. MERRILL. I believe that the most satisfactory method is that outlined by the chairman, — to operate valves in the gridiron system so that you are always sure of a flow in certain directions through the main. If you try to flush a certain group of streets by opening the blowoff and letting the mains all flow together, there may be some places at right angles to the direction of flow that you are not sure of having cleaned.

ROGER W. ESTY.* In flushing we start at the reservoir and shut off all side streets along the main line. Then we go down the main line and open up three or four hydrants, depending on the size of the main. We then go to the side streets and open only one or two hydrants. The velocity of flow is then such that you get a thorough cleaning.

SAMUEL AGNEW. We have excessively large mains. In order to flush them, you can readily see, that we have to use a lot of water. It would not do a particle of good to open a hydrant and let it run slowly. We therefore open a half dozen hydrants at once in order to get sufficient velocity to scour

*Superintendent of Water Works, Danvers, Mass.

the main. We flush our mains in the spring. Fortunately we do not have a large population on these lines at that time of year. Flushing laterals is a simple matter. They are commonly 6 or 8 in. in diameter. If any particular line gives trouble, we shut off the lines leading into it so that all our water will be drawn through the one pipe.

FRANK J. GIFFORD. Recently I had occasion to make a survey of our system to find what the delivery was and whether we needed to clean cement-lined mains carrying ground water. I cleaned about 2 500 feet in length and I also cut out an 8-ft. section of 10-in. cement-lined pipe about 100 ft. from the pumping station. On examining it I found that I had the capacity of a 4-in. pipe near the pumping station.

SAMUEL AGNEW. We recently hired one of the pipe cleaning companies to come and clean out about three miles of 14-in. cement-lined pipe. I expected that it was going to increase the flow considerably. I failed to see any material come out of the pipe. The man who did the work said that he was ashamed of himself for trying to clean it.

F. J. GIFFORD. The material in our pipe line was silt. It was so fine that it went through even the finest mesh screen we have in our wells. But it collected inside of the main and built itself up.

SAMUEL AGNEW. All the way around?

FRANK J. GIFFORD. All the way around, but it was not a growth, but merely the finest of silt coming from our wells.

H. J. GOODALE.* I have listened with very great interest to this discussion about cleaning water mains. Our mains have been flushed periodically, spring and fall, for a good many years. Our water-works system was built in 1883 and pumped water from an underground stream that was saturated with iron. This iron, of course, has been deposited all along the pipe. About four years ago we put in a Venturi meter at the pumping station and tried to melt out some joints for this purpose, but it was impossible to do so as there was so much muck in the pipes. You can flush lines to bring out dirty water and produce clean water, but you do not necessarily clean the lines. I think this may be true of many systems where they think they have cleaned the pipes after they have been flushed.

A MEMBER. If you can get a velocity of 9 ft. a second the line will be cleaned; but so high a velocity cannot be obtained on a large main, of course. If you take a gridiron system, however, shut your gates and turn the required velocity, through 6-, 8- or 10-in. pipes, you can take a great deal of material out of the line.

GEORGE F. MERRILL. I had a little experience in cleaning mains with wire. I cleaned about 5 miles three years ago. We were operating with a centrifugal pump at the pumping station, and we got a reduction of about 14 lb. head on the pump after cleaning 7 000 ft. of discharge line into a reservoir. We also found by tests that the pump was pumping something over 200 g.p.m. more. I agree with Mr. Goodale in not believing that it

*Town Manager, Middleborough, Mass.

is possible to so flush a badly tuberculated main as to clean out the silt in the bottom of the pipe.

Inspection of Fire Hydrants.

The Chairman. At New Bedford it is our practice to inspect fire hydrants twice a year and to operate every hydrant.

R. M. Roper.* At East Orange we have worked out a system of hydrant inspection through coöperation with the fire department. We have established a school for the instruction of firemen as they come new into the service, so that they will become familiar with each type of hydrant, its operation, and the difficulties that are likely to occur. In the last two or three years we have numbered every hydrant in the city. Twice a year the fire department inspects every hydrant. A form made up in card size, 4 by 6 in., which the men can readily carry in their pockets is used. On this card are shown the different kinds of difficulty that may be encountered. The reports of inspections are turned into us each morning, and inspection and repairs, unless they are major repairs, are made the same day. On the following day the report goes back to the fire chief, and he then knows that the hydrant is in good condition. Our solution of the inspection problem was not arrived at with the idea of saving the water department money. In a municipal system that would be taking money out of one pocket and putting it in the other. We have thought that through knowing the makes of the hydrants the firemen will use the hydrants more intelligently. They have also been instructed as to the relative capacities of hydrants in the different sections of the town. They know, therefore, that certain hydrants should not be pulled on to the same extent as others that are served by larger lines.

The Chairman. At New Bedford the street department is permitted to use the hydrants for certain purposes. Every time they do so, they send us a card advising us of the fact. We then follow up with an inspection. Of course the fire department, on finding any difficulties, also notifies us. We keep the hydrants in repair.

George A. King. About September 1, our hydrant man starts out and makes a systematic canvass of all the hydrants in the city. He examines every one, and makes a note of the time of inspection and the conditions that he finds. If the hydrant needs immediate repairs, they are made; otherwise he will make minor repairs at the end of his canvass. After this first examination the hydrant man makes a tour to find out whether the hydrants have dripped properly. This examination is continued through the winter. Certain hydrants that did not drip are thus located and pumped out, if necessary.

R. M. Roper. As soon as we find that a hydrant does not drip properly, we attend to it within a day. With our system of inspection we have

*Engineer and Secretary, Board of Water Commissioners, East Orange, N. J.

not had a frozen hydrant in the last nine years. One thing that has helped us to maintain this record is that no one is allowed to use a hydrant without employing an auxiliary valve which is placed by the water department. We have passed an ordinance that a fine of not more than $100 can be imposed for the use by anyone, other than an authorized person, of a hydrant without permission. Within the last two weeks we have had difficulty with one construction company and fined them $25 as a warning.

DAVID A. HEFFERNAN. At Milton we do not allow any contractors to use our hydrants. The only ones that use the hydrants are the fire department and the street department. We are fortunate in having two "call men" in the fire department, that are employed by the water department. After every fire the hydrants used are inspected by these call men.

Unfortunately we do not have a good drainage system so that we cannot properly drain our hydrants. Just before the cold weather, therefore, we put alcohol in those hydrants which hold surface water. In 37 years we have never had a frozen hydrant at the time of a fire.

PAINTING HYDRANTS.

THE CHAIRMAN. In New Bedford we have tried a number of so-called special iron hydrant paints, but finally returned to the good old "lead and oil" as the best thing. This we are using now. We paint the body of the hydrants a Brewster green, and the top, we paint white. I have not yet become converted to the yellow hydrants that the paint dealers tell us we should use.

A MEMBER. We tried out Duco paint this year, painting the base black and the tops an orange or yellow color. What the durability of Duco is, I do not know. One of the reasons I adopted Duco was to eliminate the complaints received when we did not use a quick-drying paint.

THE CHAIRMAN. Do you brush the Duco on or spray it?

A MEMBER. We brush it.

THE CHAIRMAN. Do you have any difficulty with it drying too quickly?

A MEMBER. No. It takes about an hour before it is perfectly dry.

R. M. ROPER. At East Orange we are using a compressor with a spray nozzle and Duco. We use such an amount of drying fluid that we obtain a drying period of one to one and one-half hours.

A MEMBER. Vermilion red ground in varnish seems to have been used a great deal. A short time ago the chief of our fire department was trying to find a proper paint and we tried out this color in the center of the town. The varnish fades away in about three or four months, but the red stays.

PERCY R. SANDERS. Two or three years ago we changed from black to Federal orange. It was quite a little shock to the public at first, but it got used to it, and the hydrants certainly are a good deal more conspicuous than they were before.

DAVID A. HEFFERNAN. Originally we painted our hydrants jet black

using aluminum for the dome. Recently the fire department requested the use of yellow for the dome. This we did, but now we have to go over the hydrants every year if we want them to look decent. They get more or less discolored. I always liked the aluminum tops because they would last three years.

A MEMBER. We paint our hydrants aluminum color all over. We get the aluminum powder and mix it with spar varnish. That seems to last longer than banana oil. We find it is a little better to mix the paint ourselves than to buy it already mixed.

A MEMBER. The chief of our fire department seems to think that yellow is more conspicuous than any other color. But it seems to fade away after a little while.

A MEMBER. Being the chief of the fire department as well as of the water department I am much interested in this discussion. The question of visibility at night is very important to the fire department. Aluminum color in the winter time is very poor. Nothing worse could be employed where there is snowfall.

THE CHAIRMAN. Do you prefer yellow to black?

A MEMBER. I do as far as visibility is concerned, but it fades very fast. The same is true of red. A good permanent red is hard to get.

ROGER W. ESTY. At Danvers, we have adopted a color scheme that works out very satisfactorily. The chief of the fire department likes it very much. We have a yellow barrel with a red top. We find that wherever we paint a hydrant along by the shore, where it is exposed to salt water action, the color will fade. The gloss is lost, but five miles back from the shore the gloss remains for at least a year. To keep hydrants well painted near the shore we have to paint twice a year. We give hydrants on cast-iron pipe a red top, and hydrants on cement-lined mains or small mains, indicating low pressure or lack of capacity, an aluminum top. The fire department likes this practice. It serves as a signal for caution. As far as visibility is concerned, the colors chosen show up well at night, especially when it is stormy. Yellow stands out very well against the snow in the winter-time. We have used these colors for three years, and during this time not a hydrant has been broken by being run into by automobiles. Before that three, four or five hydrants were broken every year.

INSPECTION OF VALVES.

THE CHAIRMAN. At New Bedford we include the inspection of valves with our semi-annual flushing, operating every valve and repairing those that are in need of attention. Our men were inclined to skip the big valves that required much time and effort to open. We, therefore, bought a gate-operating device mounted on a truck. Now we are assured of inspection of big valves as well as small ones. We completely close and open all valves twice a year and know that every valve is operating well.

GEORGE F. MERRILL. It is said that we do not get a real inspection of valves until a break occurs in the system. Then we are sure to find out whether the valves close or not. Many valves seem to close on inspection but we never know whether the valve is actually closed or not.

THE CHAIRMAN. You can tell pretty well, though, by the number of turns taken and the ease with which the turns are made.

PERCY R. SANDERS. How does the valve-opening machine work on a large, old valve?

THE CHAIRMAN. The machine is pretty powerful. It is mounted on a White truck and has a good engine, so that it will open any valve that can be opened. To protect the machine a pin breaks when it receives too much strain. When you know the valve is working in the right direction, however, a stiffer pin can be substituted.

A MEMBER. How small a gate can you operate with the machine?

THE CHAIRMAN. A 12-in. gate although 16 in. is the usual minimum.

SERVICE PIPES AND METERS.

A Report of the Proceedings of the Superintendents' Conference of November 9, 1927.

STEPHEN H. TAYLOR,* Chairman.

Service Pipes.

DAVID A. HEFFERNAN.† I have been asked to open the discussion on services. We have been using cement-lined pipe exclusively for our services in Milton since 1911 and have some cement-lined pipe which has been in use about 35 years. I think I was the first one to install services with a lining throughout and have been called by some the father of continuous lining.

I have spoken several times on the type of service we use in Milton and it may be partly familiar to some of you. However, I think I may be able to put some new ideas before you and with that in mind I will list the material that goes into the make-up of one of our ordinary size services.

It consists of: ¾-in. corporation cock with Hall thread; 18 in. of ¾-in., 5-lb., lead pipe with tailpiece made on each end by means of cup joints; 1-in. special hexagonal brass nipple, male ends; 1-in. iron coupling, recessed with lead lining; 1-in. wrought-iron pipe, cement-lined; 1-in. x ¾-in. brass tee head, female ends; 1-in. wrought-iron pipe, cement-lined; 1-in. malleable-iron elbow, lead-lined; 1-in. wrought-iron pipe, cement-lined for riser in case service enters building below cellar floor; 1-in. x ¾-in. iron coupling, lead-lined; ¾-in. x 2-in. brass nipple; ¾-in. lever-handle stop; ¾-in. x 2-in. brass nipple; ¾-in. x ½-in. brass elbow; ½-in. meter tailpiece.

The corporations have iron-pipe-size threads and are inserted with a Hall tapping machine. This is one of the first tapping machines made, and we have always used it, because it is very simply constructed and one model will tap from ½ to 1¼ in. For a 2-in. supply we make only a 1¼-in. tap and find that by the Venturi principle a satisfactory amount of water is obtained. I know that some cities and towns prefer to use a manifold of ¾-in. taps, but I think the 1¼-in. tap is better, because it is cheaper and does not tend to weaken the main pipe along its length.

The greatest strain in the whole service comes near the spot where it is joined to the main, and I favor a lead gooseneck at this point. Some superintendents install a rigid joint, but I believe that if they do this, with the intention of avoiding the gooseneck, they should use a swing joint of Boston street elbows. If a lead gooseneck is to be used, it is important that strong enough pipe be obtained. In our case, the connection is made

*Superintendent of Water Works, New Bedford, Mass.
†Superintendent of Water Works, Milton, Mass.

with ¾-in., 5-lb. pipe. The tailpiece on each end is sweated, by means of a blow torch, into a cup joint. One great disadvantage of lead flange-connections is that a light pipe must be used, and I am very strongly opposed to reducing the walls of the lead. With all the cup joints that we have in service now, our leaks from defective joints do not average more than one or two annually.

The 1-in. special brass nipple mentioned is attached to the tailpiece on the gooseneck. It is very similar to a hose nipple except that it has iron-pipe-size threads on both ends. These are very sturdy and are made up for us at a cost of 30 cents each. A 1-in. lead-lined, recessed coupling is attached to this nipple, and the cement-lined pipe runs from the other end of the coupling as far as the curb stop-valve.

Our pipe is genuine wrought-iron and is lined in our own shop. We use Rosendale cement because it sets more slowly, and larger batches can be mixed at one time. We reduce the 1-in. pipe to ¾-in., but believe the lining could be thinner. Our pipe is not perfect. At times we have trouble with the lining sagging, thus decreasing the water way. However, we are still working on the problem and expect to be able to improve the lining considerably. After the cement has fully set we coat the outside of the pipe with "everjet," an asphalt paint. In making cuts of the pipe a Beaver cutter is used until the cut is almost through. It is then finished with a hack saw and filed to get a square edge. Cement-lined pipe cannot be properly cut with a wheel cutter because no matter how much care is used, the wheel cutter will crumble the cement lining.

The tee head, which has female ends, is lined with lead, as are all other iron fittings. One-inch fittings are lined so that about five pipe threads will grip. Larger sizes leave more threads exposed. In threading the pipe it is well to remember not to run up too much or it will make a loose joint in the fitting. In fact, we have to saw off a few threads when they are machine-cut.

The lead lining of fittings is not as complicated a matter as one might think. It means the preparation of the proper core for elbows, couplings and tees. The actual lining operation is very simple. The lead lining in the fitting, besides protecting it from the action of the water, also acts as a washer. When the pipe is made up in the fitting it tends to bury its end into the lead, making a tight, water-proof joint. A certain amount of skill is required to make up these joints, and I believe it is best for the beginner to make up a joint and then take it apart again to make sure the joint is not buckled. Incidentally, the lining of pipe and fittings helps to solve the problem of keeping occupied, at productive operations, men whom we do not want to lay off during the winter months.

The fittings lower in the list depend greatly upon individual conditions, but you will note that, at no time, does the water come into contact with iron. The water way is made up of three materials, brass, lead and cement.

For a number of years we used cement-lined pipe, but did not line our

fittings. Electrolytic action ate away the pipe and deposited rust in the brass fittings. This was especially true at the curb stop. To overcome this action I began to line the stop and all iron fittings with lead, and since we have been installing our services in this manner, we have had not the slightest bit of trouble. Some superintendents use a curb stop with male ends and connect the pipe to it through lead-lined couplings. This plan is probably just as good as mine, but it means two more joints.

In some cities and towns the superintendent permits his service men to bend the service pipe at times as much as 45 degrees. I do not believe, however, that cement-lined pipe should receive this sort of treatment. I realize that if a trench is cut through ledge, bending the pipe may save a few dollars. On the other hand, I think that, even though the cement lining does not show evidence of crumbling after bending, a weakness is left which may give trouble in the service in a few years.

As to the charge we make for installing services, we lay the pipe all the way from the main to the meter and bill the consumer with the actual cost of the entire job, plus 25 per cent. for overhead. The town owns and maintains at its own expense that part of the service that lies in the street. Repairs to the service inside the property line are made at the expense of the owner. Renewals are paid for by the owner. Our method of charging, no doubt, may seem quite radical to many, but we have been making it for the last three years and have tried to increase our income thereby rather than by raising our water rates.

THE CHAIRMAN. I should like to be informed upon the use of cement-lined services that are subject to being emptied in the winter. It seems to me that the cement lining will become saturated with water and, when the pipe is emptied in winter, the lining will freeze. I would like to know whether the cement lining chips off, and whether it is advisable to use cement lining in such cases.

GEORGE C. BREHM.* At the Waltham Country Club we have lead-lined services that are used in the summer only. In the fall we have disconnected them and let the water drain off. I have not noticed that any harm has been done to the cement lining.

With reference to Mr. Heffernan's discussion, we have just made some interesting tests at our water depot. They were not scientifically made, but were simple practical tests, carefully carried out. All of these tests were made with cement-lined pipe. The pressure in the main, in all tests, was 90 lb. per sq. in. and the discharge was free.

Tests 1 and 2, using a rigid and a gooseneck connection on a 1-in. service 47 ft. long, gave 1½ g.p.m. more through the rigid connection than through the ¾-in. gooseneck connection.

Tests 2 and 3 showed a difference in delivery between 1-in. service with ¾- and 1-in. meters of 4.1 g.p.m.

Test 4 showed that, by replacing 15 ft. of 1-in. pipe with 1½-in. pipe,

*City Engineer, Waltham, Mass.

delivery was less than through a straight 1-in. service when a $\frac{5}{8}$-in. meter was used. In test 16, however, where the size of the meter was increased to $1\frac{1}{2}$-in., delivery was increased by 10.42 g.p.m. over straight 1-in. service.

Tests 5, 6, 7 and 8 showed that by replacing 32 ft. of 1-in. pipe with $1\frac{1}{2}$-in. pipe, delivery was increased by 5.2 g.p.m. through a $\frac{5}{8}$-in. meter, and that as the size of the meter was increased the volume delivered was as follows:

$\frac{5}{8}$-in. meter, 43.90 g.p.m.
$\frac{3}{4}$-in. meter, 46.50 g.p.m.
1-in. meter, 54.45 g.p.m.
$1\frac{1}{2}$-in. meter, 57.96 g.p.m.
Straight 1-in. service delivered 36.68 g.p.m.

Thirty-three feet of 1-in. pipe, and 15 ft. of $1\frac{1}{2}$-in. pipe delivered 36.16 g.p.m.

Test 9. Where $1\frac{1}{2}$-in. pipe was used in the foregoing tests, $1\frac{1}{2}$-in. shut-offs were used. When a 1-in. x $\frac{3}{4}$-in. x 1-in. shut-off was used with a 1-in. meter, delivery was the same as with $1\frac{1}{2}$-in. stop and 1-in. meter. By reducing the shut-off to $\frac{3}{4}$-in. the delivery remained exactly the same, 54.45 g.p.m.

Tests 10, 11 and 12 showed that by replacing 16 ft. of 1-in. pipe with 2-in. pipe the volume was increased, delivering 40.7 g.p.m. against 38.68 for straight 1-in. service, and 36.16 g.p.m. where 15 ft. of $1\frac{1}{2}$-in. pipe were used.

Delivery on these services with different sizes of meters was as follows:

$\frac{5}{8}$-in. meter, 40.70 g.p.m.
$\frac{3}{4}$-in. meter, 42.03 g.p.m.
1-in. meter, 47.47 g.p.m.

Tests 19, 20 and 21 showed differences in delivery on 2-in. service, with different numbers of taps.

One 2-in. tap, no gooseneck, 223.20 g.p.m.
One 1-in. tap and gooseneck, 120.67 g.p.m.
Two 1-in. taps and gooseneck, 171.64 g.p.m.

Tests 22, 23 and 24 showed results on 2-in. service, with different sizes of curb stops and shut-offs.

With 45 ft. of 2-in. pipe, 1-in. x $\frac{3}{4}$-in. x 1-in. curb stop and 2-in. shut-off, delivery was 85.56 g.p.m.

With 45 ft. of 2-in. pipe, 2-in. curb stop and 2-in. shut-off, delivery was 159.43 g.p.m.

With 45 ft. of 2-in. pipe, 1-in. curb stop and 1-in. shut-off, delivery was 148.80 g.p.m.

It seems to me that, as a 2-in. valve and a 2-in. shut-off each cost about $12.50, there can be a great saving on 2-in. services by reducing the curb stop and shut-off to 1 in.

Tests 30 and 31 showed the difference in delivery of new cement-lined pipe, and new unlined, galvanized-steel pipe.

Forty-seven feet of 1-in. cement-lined pipe, delivered 39.43 g.p.m.

Forty-seven feet of galvanized-steel pipe, delivered 43.52 g.p.m.

The foregoing tests were made simply to prove or disprove the claims that greater volume could be obtained by increasing the size of the pipe. We are still working on other tests similar to these, both on the short and long sides of the street and with setbacks of 15 and 25 ft.

SAMUEL AGNEW.* Reverting to Mr. Heffernan's charges for services, I wonder how the customers take the matter of charging the whole of the bill plus 25 per cent. to them, and having the city claim ownership of the pipe in the street.

DAVID A. HEFFERNAN. The only complaint we have had was from the builders. At first there was considerable argument, but now they have got used to the charge. When they sell a house they add enough to the cost of the house to pay for the service charge.

THE CHAIRMAN. We had pretty nearly the same experience in New Bedford. We used to have a charge of $2 to the street line, which, as we all know, nowhere nearly represented the cost. The city still held the ownership of the pipe in the street. A few years ago we needed more money so we figured the average cost of all the services laid during a certain year and made that our fee instead of $2. The charge varies with the size of the pipe from $31 to $35, which in some cases is more than the cost, and in some cases less, and averages less. We still claim the ownership of the pipe in the street and have had no trouble. It is simply an advance from $2 to $31 for the same thing.

SAMUEL AGNEW. That is well enough for municipally-owned plants, but I would like to know how some of our private corporations fare.

THE CHAIRMAN. It seems to me that a private corporation gets enough more for water to make up that difference.

HENRY T. GIDLEY.† It seems to me personally that if it costs more to furnish water to people one should raise the price of water rather than charging the man who is building a new house.

THE CHAIRMAN. The other side of the argument is: Why should the city make any one a present of $31 worth of material and let the other water takers jointly pay for it? There are two sides to the argument. But a private water company is selling water at profit, or it would not be in business, and this is part of the overhead. The municipal water system is supplying the taker at cost practically, therefore why should not the taker pay for his own installation? It is open to argument on both sides.

DAVID A. HEFFERNAN. We figured, last year, the cost of our work on services, and the average cost was about $1.33 a foot for 1-in. service. I claim that it is the best principle for the water department to do the work from the street main to the cellar. If we run only to the street line, it gives the plumber a chance to run a pipe of poorer material the life of which, due

*Superintendent of Water Works, Hingham, Mass.
†Treasurer and Superintendent, Water Co., Fairhaven, Mass.

to the action of the water, is only seven or eight years. We give the owner a service that will last 40 or 50 years.

With respect to the use of goosenecks I think our whole trouble is due to the fact that superintendents or water officials do not consider the proper pressure. To illustrate this I shall give a few figures of the weights of lead used in various places as follows:

Quincy, Mass., pressure 95 lb., $\frac{5}{8}$-in. 3 lb., $\frac{3}{4}$-in. 4 lb., 1-in. 5 lb.

Reading, Mass., pressure 90 lb. maximum, 45 lb. minimum, 1-in. 4 lb.; $1\frac{1}{4}$-in. 5 lb.

Spencer, Mass., 140 lb. maximum, 80 lb. minimum, $1\frac{1}{4}$-in. 5 lb.; 1-in. 4 lb.

Springfield, Vermont, 165 lb. maximum pressure, $\frac{3}{4}$-in., 4 lb.; 1-in. 6 lb.

No wonder the pipes burst. The pipes are too light.

We use $\frac{3}{4}$-in. 5 lb.; 1-in. 6 lb.; $1\frac{1}{4}$-in. 9 lb.; $1\frac{1}{2}$-in. 10 lb. 2-in. 15 lb.

It is impossible, in using a patent flange, to employ the $\frac{3}{4}$-in. 5 lb., or 1-in. 6 lb., lead. If it is heated over 90 degrees the pipe will sag. If solder is used with a swage joint, the solder will make a firm bond and take up the weakness in the pipe. But if a flange is used the weakness will always be there, and the pipe will split along its length.

SAMUEL AGNEW. We use the flanges of which Mr. Heffernan has spoken. I would not want one of my men to bend a lead pipe over the flange. He is supposed to hold it with his hand when bending it and to bend the pipe away from the lead. I have had no acquaintance with lead pipe splitting, and I fail to see why the pipe should be stronger when a brass nipple is cupped into the end of the pipe than when it is flanged over in a lead flange coupling. The strength of the pipe, I think, is the same. If a man bends a pipe directly over a coupling, it will, naturally, cut. If he does the same thing with the joint, he is apt to crack it right at the end of the nipple. I fail therefore, to see, where there is any advantage in cupping the gooseneck.

DAVID A. HEFFERNAN. I claim that by using the flange you split the pipe, or weaken it. In a cup joint, if there is any weakness the solder makes a firm bond and offsets the weakness.

SAMUEL AGNEW. We have put in many thousands and seem to have had no trouble.

ALBERT W. MOORE.* I have control of over twenty water companies, and we use the flange joint altogether. We never have had one of them give out in use, and I think the flange is a great deal better than Mr. Heffernan's way of making up the lead connection. I think it strengthens it rather than weakening it. We have probably 25 000 in service in different companies, and we have never had any trouble.

GEORGE F. MERRILL. We are at present having trouble with the old style gooseneck made with cup joints. Most of the trouble is caused by the brass nipples, through which the water will eat small holes. In other

*Director, Northern Water Co., Hingham, Mass.

cases the solder will give a little and cause a leak. We use the lead flange couplings entirely and have had no trouble with them. We employ double extra strong lead, and couplings that are made for that weight of pipe. I think the solder or cup joint is a thing of the past. You can make the other ones much quicker.

F. M. COLE.* We use lead flange couplings altogether, and I firmly believe in their use. We are putting in 400 or 500 services a year, and have had no trouble. We use 3½- and 4-lb. lead in the city proper. Our range of pressure in the center of the city is from 68 to 72 lb.

W. GUY CLASSON.† We are making goosenecks out of copper with a flange joint. We feel they are much stronger and cheaper in every way. We have found no trouble with them.

THE CHAIRMAN. Do you use thin copper tubing?

W. GUY CLASSON. Copper tubing, similar to that used on automobile gasoline lines.

HOWARD M. KING.‡ We have used a rigid connection for at least 25 years. We have also used some lead connections. Every winter, and sometimes during the warm weather, we have to take some of them up. They split. We have over 40 000 rigid connections in the city and have very little trouble with them, so I do not care for the lead connection myself.

TESTING AND REPAIRING WATER METERS.

F. M. COLE. At Brockton we have some 22 or 23 different types of meters. Our meters are read monthly, and we anticipate a use of 300 to 350 cu. ft. for each tenement of ordinary size with modern improvements. If the meter reading falls below that, we take it out. If it goes much above that we send down an inspector, and he looks the property over and sees whether he can find any leaks.

We send a man and a helper to take out meters. The average time to remove a ⅝-in. or a ¾-in. meter is about 20 minutes. The men cover a whole district. They do not take one meter here and another there.

The meters are brought to the shop where one man takes the bolts out, washes the meter and turns it over to the repair men. We have two repair men. We have others too, who do some repairing and some testing.

Our average cost of repairing meters, outside of the parts used, is from $2.50 to $2.75. The meters are tested before they are returned.

THE CHAIRMAN. At New Bedford we try to take out all of our meters after five years' service. I say try, for I am afraid we do not always succeed.

It seems to me that there should be some period, either measured by time or amount of water passed, after which meters should be overhauled whether they appear to be all right or not.

ALBERT W. MOORE. We check up our meters on the basis of a con-

*Brockton Water Works, Brockton, Mass.
†Superintendent, Water Works, Leominster, Mass.
‡Superintendent, Water Department, Springfield, Mass.

sumption of 200 000 cu. ft. After passing this quantity they are tested and returned. As a rule, registration is accurate within 2 or 3 per cent.

F. M. Cole. We plan to take out our meters whether they need it or not.

George F. Merrill. There are three elements that enter into the necessity of taking out a meter: the question of time, the quality of water, and the amount of water that the meter has passed in relation to its size.

Some claim that surface waters have less effect on meters than ground waters. Ground waters generally carry more sediment or sand that wears down the meter walls. It has been my experience with surface water that some meters work seven or eight years without registering inaccurately. In my present position I find that they require attention in three years.

Roger W. Esty. It is very easy to take out a $\frac{5}{8}$- or $\frac{3}{4}$- in. meter and to repair it. I would like to hear what the experience has been with testing larger meters. Are 2-, 3-, 4-, 6- and 8-in. meters taken out for test, or are they not tested at all?

The Chairman. At New Bedford, I am sorry to say, we are only equipped to test meters up to 3 in. The larger ones we have to send back to the factory.

F. M. Cole. We repair all of our meters. Some of them we test on the service, by obtaining a correct meter from the factory and comparing it with the 4-, 6- or 8-in. meter.

George F. Merrill. We repair all meters, with the exception of the larger ones. For the larger sizes we order calibrated parts from the factory, and I think it oftentimes saves us a lot of money and expense to put new parts in on a 3- or 4- in. meter.

Roger W. Esty. I think that, generally, cities and towns spend too much money on testing smaller meters that do not average more than $10 or $15 a year revenue, while, on their larger services, they do not give enough attention to the meters. We are actually testing all of our big meters twice a year, and that is not half often enough.

We made a survey of our system in 1920 and found that our large meters were running slow. By changing these meters on certain lines from which our revenue was $1 800 per quarter we increased it to $4 000 or $4 200 per quarter.

We spent about $5 000 in changing over meters about three years ago, and we have by-passed every large meter. We have set them with flange fittings, with a Crispen sleeve, to make it easy to remove the meter, and we put three gates around the meter, one before, one after and one on the by-pass line. We feel that we more than save the expenditure of perhaps $150 on one of our large meters sometimes in a month's registration.

Our meter revenue has more than doubled since we made the change, and we are going to test large meters three times a year in the future.

We test our meters by running a fire hose to a 2-in. meter from the test tee. We do not test for more than a 2-in. meter will carry, about 175 g.p.m.

TUBERCULATION OF CAST-IRON PIPE.

BY CHARLES W. SHERMAN.*

[*Received April 30, 1928.*]

It is probable that some one must have observed the formation of tubercles in cast-iron pipe within a few years after pipe of this material began to be used, but if any record was made of the fact it is not readily discoverable. About 1830 French engineers began to write about tuberculation, and a little later similar accounts appeared in England. Comparatively few engineers or scientists had any idea of the extent to which tuberculation might occur, or of its effect upon the pipe and its carrying capacity. It does not appear that any consideration was given to the matter when Boston started the Cochituate Water Works in 1848. Within a very short time, however, the effect of tuberculation upon the carrying capacity of the uncoated cast-iron pipes became so apparent that the Water Board caused extensive investigations to be made by the City Engineer and by Professor E. N. Horsford, one of the best-known chemists of his time. The reports of these investigations are quite as valuable today as they were 75 years ago, but they are known only to few, and the old reports in which they appeared are not generally accessible. For these reasons they are reproduced in this paper.

It is of interest to note that the efficiency of a cement lining in preventing tuberculation was recognized as early as 1835.

The following quotation is taken from the annual report of the Cochituate Water Board of Boston for the year 1852.

"Among the variety of topics noticed in the Report of the Engineer, deserving the consideration of the City Council, there is one which we consider to be eminently so. We allude to the effects which are found to be produced, on the inner surface, of all the iron mains and pipes, by the action of the water.

"The attention of the Water Board was attracted to the subject, soon after its appointment; for although the pipes had then been in use less than three years, those effects were already quite obvious and striking, and in fact had been noticed some time previous. They have since then been carefully watched, and the valuable assistance of Professor Horsford has been engaged, for the purpose of ascertaining as far as is practicable, their origin, their probable progress for the future, and the means which might be relied upon, for the purpose of preventing, arresting, or retarding them. The two Communications of Professor Horsford, describe with minuteness the present appearance and state of the interior of the mains and pipes, as does also the Report of the City Engineer.

"The effects to which we now allude are the peculiar changes which have been produced on the iron itself; and they consist in

*Consulting Engineer (Metcalf & Eddy) Boston, Mass.

"1. The absorption of the iron in certain places, and the formation in its stead of a substance resembling plumbago.

"2. The gradual development of local accretions or tubercles, in the interior of the pipes, by which the flow of water is impeded, and their capacity diminished, so that the object for which they were laid becomes imperfectly accomplished, and an apprehension is excited that they may be so far closed up as to be useless hereafter.

"This subject has received but little scientific investigation, till within a few years, notwithstanding its very obvious importance, and although the evils must have existed ever since cast-iron has been used for such purposes. It is one, however, of no little importance to the City, as there is involved in it the question of the present and future capacity of all the iron pipes which have been or are to be laid, at no small expense, and of their consequent adaption to the purpose for which they are used, and also of their ultimate durability. The Water Board have therefore thought that it would be interesting and useful to lay before the council somewhat in detail, not only the present condition of the pipes belonging to the Water Works of this City, in relation to the subject; but also the result of such inquiries, as they have been able to make, into the extent of the same evils in other places, and the efforts which have been made to ascertain their nature and origin, and to provide a remedy for them, and the success of those efforts.

"The first notice taken of this subject which we have seen, appears in the transactions of the French Academy of Sciences, for the year 1836 (*Comptes Rendus*, v. 3, p. 131). It is a note by M. Vicat on the subject of a coating to prevent the development of Tuberculous accretions in cast-iron pipes for conducting water.

"He states that a report, printed at Grenoble, November 22, 1833, by order of the Municipal Council, called the attention of the public, to the rapid as well as unforeseen, filling up of the large cast-iron main, of the Chateau d'Eau, in that town. The formation of numerous tubercles of hydroxide of iron, began to show itself, shortly after the water was let on, by a perceptible, though slight diminution of the discharge. The development of the accretions, however, as was proved by many accurate measurements, soon increased so much, that the supply of the Chateau, which had been in 1826 about 1400 litres (about 370 wine gallons*) a minute, was gradually reduced in 1833 to 720 litres, (about 190 wine gallons,) showing a loss of nearly one-half. A good deal of alarm was excited by it, and an attempt was immediately made by eminent chemists, to ascertain the cause, and reconcile the phenomenon with various theories. A commission, consisting of Engineers and others, was also appointed which discussed at Grenoble, the means of destroying this kind of ferruginous vegetation (as it is called in the Report), or arresting its progress. In the meantime new measurements indicated that in less than five years the pipes would probably be so obstructed that the water would cease to flow through them. Two members of the Commission, Messrs. Guemard and Vicat, Engineers in chief, being persuaded that the tubercles were formed at the expense of the castings, applied themselves to the discovery of some coating, which would be at the same time cheap, indestructible, and capable of preventing oxidation. After two years of experiments, they considered it sufficiently proved, that hydraulic cement applied about 2½ millimeters thick (0.0984 in.) is of all compositions, combining facility of application and cheapness,

*A "wine gallon" is 231 cu. in., the present U. S. standard gallon.

that which adheres the best to the castings, is the most indestructible, and prevents most effectually all oxidation, and consequent formation of the tubercles. With this composition, they recommend that the interior of the mains should be washed over, by means of a sponge, proportioned in size to the diameter of the pipe.

"M. Vicat also states that, owing to unforeseen causes, the tubercles on the grand Conduit for supplying the fountains appeared to have reached their limit of development, as several exact and careful measurements which had been made in May, 1836 left no doubt of the fact. He says, therefore, that it might be affirmed that they were then stationary. He raises a question, however, as to their continuing so, for the future.

"In the same volume (p. 462), there is an extract of a letter from M. Prunelle to M. Arago on the subject of the tubercles which had formed in the pipes of the conduit at Vichy. Those pipes, which were gray castings, had been laid twenty-six years previous. The quantity of water from them had diminished from day to day, and among other obstacles to its passage, they at last discovered tubercles as large as hens' eggs. The water passing through them was found not to contain a trace of iron.

"And there is also one from Sir John Herschel to M. Arago (p. 506), which mentions, that pipes for conducting water, at the Cape of Good Hope, were affected in the same way as those at Grenoble, and that the difficulty had been remedied by a coating of Roman cement.

"In the transactions of the same Academy for the next year, (*Comptes Rendus*, 1837, v. 4, p. 190,) there is a Report from a Committee on a memorial offered by M. Payen, on the subject of local concretions or tubercles, in iron water pipes. The following is the result of M. Payen's experiments and reasoning: Waters which have a feeble alkaline reaction possess the property in presence of air and sea salt, of producing on wrought or cast-iron which they moisten, local concretions, which preserve the remainder of the surface free from all change. And these effects vary according to the proportion of the different salts, the breaks of continuity, and the foreign bodies adhering to the surface of the metal. That to this cause may be attributed the concretions in the pipes at Grenoble, the waters at that place having a feeble alkaline reaction, owing to the presence of carbonate of lime, and being slightly alkaline. And that it may be concluded, that wherever there is a want of homogeneity in the cast-iron pipes, which convey water slightly alkaline and saline, tubercles will be found at the points where heterogeneity exists.

"An analysis of the accretions gave the following results:

"Protoxide of iron	0.210
Peroxide of iron	0.582
Carbonic acid	0.050
Water	0.013
Silica	0.013
	1.000

"In 1837, the subject attracted the attention of the British Association for the Advancement of Science, and under its auspices, a very elaborate investigation of the action of air and water, whether fresh or salt, clear or foul, and at various temperatures, upon cast-iron, wrought-iron and steel, was made by Mr. Robert Mallet. Mr. Mallet commenced in 1838, and continued until the year 1843, a very complete course of experiments on the subject. They were made on eighty-two different sorts of iron, (chiefly

cast-iron) immersed in clear and foul sea water and clear and foul fresh river water, for two different periods, the first period occupying 387 days, and the last, 732 days; and, at the end of each period, the specimens were taken up, carefully examined, and weighed. The results of the experiments, and Mr. Mallet's deductions therefrom, were communicated from time to time, to the Association, in three Reports made by him, which were published in the Reports of the Association, for the years 1838, 1840 and 1843.

"In his first Report, which is devoted to the consideration of the then existing state of chemical knowledge of the subject at large, he remarks, that notwithstanding the innumerable uses to which iron had been applied, for the purpose of supplying the social wants of man, during the preceding half century, yet our information on the subject of its durability, and the causes likely to impair or promote it, was scarcely more advanced than it had been twenty years previously, and that while the chemist was not precisely informed as to the changes which air and water produce on it, the engineer was without data to determine what limits the corroding action sets to its durability. Nor was it known with certainty, what properties should be chosen in wrought or cast-iron, that its corrosion might be the least possible, under given circumstances. Neither was our actual knowledge more advanced as to the variable effects of corrosive action, on the same iron, of different waters, such as are commonly met with, containing their usual mineral ingredients in solution (exclusive of the better understood cases of mine-waters).

"The investigation was therefore undertaken for the purpose of throwing light on these topics, and there was of course involved in it a great extent of inquiry into the durability of the metal, the forces which were likely to impair it, the mode in which these forces would act, what would be their results, and the means of arresting their progress.

"The Board can merely state some of the general laws regulating the action of fresh water on iron pipes which Mr. Mallet considers as previously known, or established or confirmed by his experiments.

"He found that any sort of iron, cast or wrought, corrodes when exposed to the action of water holding air in combination, in one or other or some combination of the following forms, viz: 1. UNIFORMLY, or when the whole surface of the iron is covered uniformly with a coat of rust, requiring to be scraped off, and leaving a smooth red surface after it. 2. UNIFORMLY WITH PLUMBAGO, where the surface as before uniformly corroded, is found in some places covered with plumbagenous matter, leaving a piebald surface of red and black after it. 3. LOCALLY, or only rusted in some places and free from rust in others. 4. LOCALLY PITTED, where the surface is left as in the last case, but the metal is found unequally removed to a greater or less depth. 5. TUBERCULAR, when the whole of the rust which has taken place at every point of the specimen has been transferred to one or more particular points of its surface, and has there formed large projecting tubercles, leaving the rest bare.

"The great elements of difference of corrosion as respects the iron itself appear to be:

"1. The degree of HOMOGENEITY of substance of the metal, and especially of its surface.

"2. The degree of DENSITY of the metal, and state of its crystalline arrangement.

"3. The amount of UNCOMBINED CARBON or suspended graphite contained in the iron.

"And therefore that the more homogeneous, the denser, harder, and

closer grained; and the less graphite, the smaller is the index of corrosion.

"In fresh water combined with air, corrosion proceeds fastest in water from 175° to 190° Fahrenheit.

"And it is in direct ratio with the volume of air, —

"And ceases entirely in water deprived of air.

"Fresh water may hold so much combined air, (not to speak of carbonic acid,) as to act more rapidly than sea water. CARBON as it is known exists in iron as diffused graphite in a crystalline form, and as combined carbon; the dark gray and softer irons contain more of the former; the lighter and harder irons, more of the latter. Now the latter kind have the property of being much less uniform or homogeneous in surface when cast under similar conditions, than the former; while the highly graphite irons, though more uniform in large specimens, are the least dense and softest in texture: hence, the bright gray irons of high commercial marks, the Nos. 1 and 2, while they are the most valuable for construction, are also the most durable. And, in general, the result of the experiments show that cast-iron with low commercial marks, the Nos. 3 and 4, etc., corrode locally and generally become pitted, while the high marks, 1 and 2, etc., corrode with considerable uniformity over the whole surface.

"The rate of corrosion is a decreasing one, at least when the plumbago and rust first formed has been removed. When, however, this coating remains untouched, the rate is much more nearly uniform, and is nearly proportional to the time of reaction, in given conditions. In some cases, even where the coating had been removed, an increment in the rate had taken place. And it is observable that this almost uniformly occurred in those specimens which had the smallest amount of corrosion at their first immersion. Thus there was a tendency to a greater equality in the index of corrosion in all the varieties of iron at the second than at the first immersion.

"Homogeneity of surface and texture, or the contrary, are by far the most important circumstances which vary the amount of corrosion of cast-iron by air and water.

"And the rapidity of this corrosion is not so much dependent upon the chemical constitution of the metal, as found in commerce, as it is upon the state of molecular arrangement and the condition of its constituent carbon.

"It is certain that the blackest cast-irons, viz., those which contain the largest quantities of uncombined carbon or graphite in a mere state of mixture, are acted upon by water and air the most rapidly. The gray or mottled iron as containing a less quantity of uncombined carbon, and having a denser structure, is less acted upon. And the varieties of iron which present scarcely any symptons of a crystalline texture at all, but still are grained or mottled, are those which are the least susceptible of alteration or decay.

"Chilled cast-iron, of every sort, upon the whole, corrodes faster than the same sort of iron cast in green sand. And this is owing to the greater want of homogeneity in its surface, than in that of any other sort of casting, by which the voltaic action produced at its surface, increases the corrosion to a greater extent, than its great density and hardness and small amount of uncombined carbon are capable of retarding it, compared with other sorts of cast-iron. When, however, iron moulded in sand is exposed to corrosion, this takes place with considerable uniformity over the whole surface. But in chilled castings, the largest portion of the surface remains unchanged, and the corrosion is nearly or wholly confined to certain spots, and gradually produces large tubercular concretions.

"The size, and perhaps the form of iron casting, forms one element, in the rate of its corrosion in water. Because the thinner castings having cooled much faster and more irregularly than the thicker, are much less homogeneous, and contain veins and patches, harder than the rest of their substance; hence the formation of voltaic couples and accelerated corrosion.

"He estimates that from three-tenths to four-tenths of an inch in depth, of cast-iron one inch thick, and about six-tenths of an inch of wrought iron, will be destroyed in a century, in clear water.

"He also states that the officers of the French artillery, after a number of experiments, found that the corrosion of iron by air and water, is greater in proportion to the purity and goodness of the coke, with which the iron is made, and that it is altered less, when made with charcoal, than with coke; and that iron cast in dry sand, or in loam moulds faced with charcoal, oxidates much less speedily than when cast in green sand; and that chilled cast-iron, or that in iron moulds, is least of all susceptible of the change.

"As to the nature and origin of the peculiar change which takes place in the conversion of part of the metal into an entirely different substance, but little information, beyond what was already known, can be obtained from these reports. It is stated in the introductory one, before the result of the experiments was ascertained, as a fact, first observed by Dr. Priestley, that cast-iron being immersed in sea water for a length of time has its metal wholly removed, and becomes changed into a substance analogous to plumbago, mixed with oxide of iron, which frequently, though not invariably, possesses the property of heating and inflaming spontaneously, on exposure to air; but that it is yet by no means clear, how it is produced, what is its precise composition, and to what is owing its rise of temperature on exposure to air; that malleable iron, under circumstances but little understood, is also subject to this change; and also from various statements of others, it would seem that both malleable and cast-iron are affected in the same way, when immersed in water holding in solution alkaline or earthy salts or acids.

"The subsequent experiments throw no new light on the cause and nature of this singular phenomenon. They show, however, that the same effect is produced by the action of air and fresh water; and this is too well corroborated by our own experience.

"In regard to the opinion expressed by M. Vicat, that the tubercles at Grenoble were stationary, he remarks, that it must be obvious that the rate of increment of these must be a decreasing one; but that he does not perceive anything to set a limit to their accretion, except the stoppage of corrosive action. Mr. Mallet considers that in tubercular corrosion, the whole of the rust which has taken place, at every point, is transferred to one or more particular points, and thus forms the projecting tubercles, leaving the rest of the surface bare. The sole essential circumstance to tubercular corrosion, he states to be the want of homogeneity, in the metal corroded; and he therefore controverts the opinion of M. Payen, before cited, that the cause of the phenomenon is partly to be attributed to a slight alkaline reaction of the corroding water. This peculiar effect, too, is confined to chilled or unequally cooled cast-iron, to mottled iron, and to damasked wrought-iron, or that of mixed constitution; and in all, it appears to result from heterogeneity of composition, and it is therefore unnecessary to call in, to aid the explanation, the preservative action of alkaline solutions.

"The important problem of preventing the corrosive action, of the water, by coating the interior surface of the pipe, was a principal object of Mr. Mallet's experiments. He did not, however, discover anything which would have the desired effect. Of ten kinds of paints and varnishes, laid

on with great care, not one would completely prevent corrosion for a single year — or remain perfectly adherent or undecomposed for that time. With regard to M. Vicat's proposition, previously stated, (in the *Comptes Rendus*, v. 3d, p. 181,) of coating the pipes with hydraulic cement, he thinks that though this would no doubt for a time diminish corrosive action, it is much to be feared it could have but little permanence, when the current was rapid, and, should the water contain much earthy matter, the tendency of this to deposit and adhere to the pipes, must be fatally increased.

"The various results of Mr. Mallet's experiments are exhibited in a full series of tables, which present to the Engineer, as he thinks, 'sufficient data to enable him to predict the term of durability, and allow for the loss by corrosion of iron in all conditions, when entering into his structures.'

"The last information, to which we shall refer on this subject, is contained in a paper on Tubercles in Iron Pipes, by M. Gaudin, Engineer of Bridges and Roads, published in the *Annales des Ponts et Chaussees*, for November and December, 1851. He states that the iron conduit at Cherbourg, constructed between the years 1836 and 1838, of white casting, about 2 460 metres (nearly 1½ miles) long, had become everywhere coated with tubercles, which, in some places, had an elevation of from 4 to 5 centimeters, (1.575 to 1.968 inches,) so that the orifice of the pipe which was, when laid, 18 centimeters (about 7 inches) in diameter, had been reduced to less than one-third its original section. The consequence of the diminution of the orifice, joined to the enormous loss of head occasioned by the additional friction, had deprived many of the workshops at the end of the conduit of a supply, prevented the simultaneous playing of the fountains, and made the supply of the grand Reservoir impossible, or very feeble.

"The tubercles were very broad at their base, and very strongly adhering to the surface of the pipe, and could not be removed, except by heating the pipe to a red heat, or by a forcible action of an instrument. They were of a greenish brown color, and testaceous structure, and, on exposure to the air, assumed the color of yellow ochre, a sure sign of the oxidation of part of the iron which entered into their composition. Their density was almost 3.362. A chemical analysis gave the following results:—

"Peroxide of iron, 96 to 98.
Silex and Alumine (argil) 4 to 2.
Chloride of Sodium — traces.
Sulphate of Iron — traces.

"They were, therefore, almost entirely free from (at least as far as regards the iron which they contained) the elementary matters contained in the water in solution; and, indeed, they were not derived from substances which it could hold in solution. The water was free from color, taste or smell, and its specific gravity nearly that of pure water. It showed, on analysis by chemical tests,

"A very small quantity of carbonic acid.
A small quanity of calcareous earth.
A small quantity of sulphate of soda.
A positive quantity of chloride of soda.
Little or none of the metallic salts.
And little or no iron.

"A more recent analysis of the water, taken before its passage through the Conduit, showed its density to be scarcely different from distilled water;

to reagents it only showed chlorides, and those, chlorides of sodium; there was no trace of lime, nor sulphates, nor iron.

"He considered it certain, that the iron in the tubercles was to be attributed exclusively to an alteration which had taken place in the pipes themselves, no matter what the casting might be, whether white or gray. And as, notwithstanding this alteration, there could not be seen in the pipe, even with a glass, after it had been well rubbed, any difference between its texture and that of new casting, he concludes that the deterioration must have taken place over the whole surface indiscriminately, in the same way. He calculates that the greatest thickness of the layer which could have been thus removed in thirteen years was 0.00025 metre (0.0098 inch); or 0.0002 metre (0.0075 inch) annually.

"In reference to the obtaining some remedy for the evil, he observes, that waters the most pure and most proper for the ordinary necessities of life afford no exemption, since it appears invariable that the tubercles are in an especial manner developed by the presence of very small quantities of sea salt, which almost all waters contain. And that chemists and engineers have therefore recommended the forcing of linseed oil by great pressure into the metal, and also coatings of mortars and hydraulic cements and bituminous coverings. There was a great limit, however, to the efficacy of all of them. At Cherbourg, pipes which had been laid down not more than three years previous, and which had had linseed oil forced into them by hydraulic pressure, already showed traces of tubercles, some of which had attained an elevation of 4 and 5 millimetres (0.157 to 0.197 inch).

"Coatings of mortars and hydraulic cements cannot be applied without great difficulty, and must be in very thin layers; and the whole surface is therefore not covered, leaving points where the tubercles are developed. Bituminous coatings could indeed be applied by immersion in hot baths composed of those substances, but these means, if efficacious for a time, must have their limit, when the friction of the water shall have worn away the thin covering; and then the same difficulty would be felt as before. He thinks, therefore, that the only means on which could be placed a hope of certain preservation of the iron, would consist in the discovery of some compensating agent against the magnetic or chemical action which causes the formation or development of the tubercles, and that the agent employed should not affect the quality of the water, and that its application should be simple and not expensive. Such an agent, however, had not been discovered. Mr. Gaudin then proceeds to describe his mode of removing the accretions by mechanical means from time to time when it should be necessary.

"The foregoing statement contains a very brief analysis of the investigations which have been made, in other places, of the nature, origin, and mode of remedying the evils now under consideration, so far as they have come to our knowledge. We annex to it the able and interesting communications of Professor Horsford, and refer, to the report of the City Engineer, to show the extent of our own experience in relation to them.

"It has been hoped that by bringing to the notice of the Council all the facts which we have been able to accumulate, and offering even an imperfect sketch of the researches made on the subject, we might enlist the attention not only of those who are similarly interested with ourselves, but also of men of science, and of those who are engaged in the production of the metal itself, or in the great variety of manufactures and constructions in which iron is employed. And that if this object could be effected, it might be the means of ascertaining hereafter some mode either of preventing

the evil in its origin by improvements in the castings, or of arresting or retarding its further progress by the intervention of some preparation for covering and protecting the surface; or, of obtaining a temporary remedy by providing a mode of removing the obstructions as they from time to time appear.

"Undoubtedly, the most important change which takes place on the inner surface of the pipes, as far as relates to any immediate results, is the production of the accretions. The formation of plumbago or something like it, in the place of the iron which has been absorbed, does not indeed protect the metal beneath it, and the action continues, perhaps even with a slightly accelerated force; but, according to the French and English authorities, its progress is so slow that many years must elapse before any serious consequences from it alone would be likely to happen. It is probable that the only way to prevent this action will be found in coating the surface with some composition which will shield it. We cannot anticipate what success may attend future attempts to discover such a composition; up to the present time, we believe, they have all been quite fruitless.

"But, with regard to the accretions, their growth has been more rapid and important, so much so, that our 36-inch and 30-inch mains have become already, in consequence of the actual diminution of their area and also of the additional friction which has been occasioned, scarcely superior in capacity to those of 34 and 28 inches; having a clean surface; and we have had sufficient experience on the subject to convince us of the impolicy of making use of wrought-iron service-pipes at all, or of cast-iron ones, of less than 4 inches in diameter.

"We cannot indeed, at present feel any certainty as to the extent to which the tubercles will ultimately increase, and think there is some prospect that they may become stationary, or at least have their progress much retarded. As their origin is, however, attributed by the English authorities solely to the constitution of the iron itself, and by the French, and to some extent by Professor Horsford, partially to the same cause, it is possible that improvements may be made in the manufacture of the metal, or the casting, by which it may be rendered more homogeneous, and their formation be thus prevented; and, in the mean time, reference may be had to this quality of the metal in selecting the castings, whenever it shall be possible.

"It is the intention of Professor Horsford, if he can do it consistently with the performance of his other duties, shortly to obtain an analysis of the iron, from our own pipes, where an unlike tendency to accretions is noticed; which may throw some light on the point of homogeneity."

FIRST REPORT OF PROFESSOR HORSFORD.

"CAMBRIDGE, Jan. 14, 1852.

"THOS. WETMORE, Esq.,
President of the Cochituate Water Board.

"Dear Sir: — In reply to your favor of the 5th instant, in relation to the accretions in the Cochituate iron mains, I have to regret that my investigations thus far have thrown but little light upon the question of most importance; to wit, How far will these accretions extend?

"A brief statement of the present condition of the pipes will show the bearing of this inquiry.

"At the two points near Dover Street, where one of the main iron pipes was taken up for repairs in the last autumn, there were found, upon the

interior surface of the pipe, nodules varying from half an inch to three inches in diameter at the base, and having a height of from one-quarter to a little more than half of an inch. Some of them were of a reddish, others of a dirty yellow color, and those of each color invariably in a group by themselves. They presented concentric structure within, and rested in many cases upon slightly elevated portions of the surface of the pipe. These elevated portions were co-extensive with the inferior surface of the nodules, were of a dark brown color, and crumbled at once to powder upon being scratched with a knife.

"Portions of the surface of some sections of pipe were quite free from accretions. In some areas, the accretions were small; in others, most were large. There seemed to be no tendency among them to gather upon the bottom rather than upon the top and sides.

"Upon placing one of these nodules in warm hydrochloric acid, the reddish and yellow part dissolved to a dark red solution, leaving a white jelly-like residue, which, under the microscope, appeared an amorphous inorganic mass. Chemically examined, the latter proved to be silica, and the red solution, iron. A quantitative analysis of the whole, gave

"Peroxide of iron	= 91.74 per cent.
Silica	= 1.28 per cent.
Water, trace of organic matter, and loss	= 6.98 per cent.
	100.00

"The yellow nodules, upon being heated, became red. As all the nodules had been subjected to heat in melting out the lead connections between the sections of pipe, it was evident that the difference in color was to be ascribed solely to the unequal heat to which the red and yellow nodules had been exposed. This explained the occurrence in such well defined groups, of the nodules of either color.

"The suggestion that the accretions might be due to the growth of some kind of vegetation, in which were lodged particles of the ochreous matter in suspension in small quantity in the Cochituate water, and which gives to it, its occasional faint wine color, which is found on the bottom of the tunnel, and which accumulates in the filters, was not sustained by microscopic examination. The ochrey deposit is composed of organisms, of which the accompanying card contains several of the best defined and more remarkable forms.* Of these, only an occasional one is found in the accretions.

"There are reasons for believing the slight elevations of surface observed immediately beneath the accretions to be due to changes in the texture of the iron arising from the growth of the accretion, and not be an original irregularity of the casting; and further, for believing that the accretions are indebted for their iron to the surface upon which they rest, and not at all, or but very slightly, to the water which flows over them.

"I have wrought iron pipes of 1½ inches calibre, which are coated with accretions interiorly, and which, in twelve months, have been eaten through from within outward, by the circulation of cold Cochituate water. I have others of the same diameter, which, in three months, have been eaten through by the circulation of hot Cochituate water.

"I have another pipe, one inch in diameter, which in twelve months

*The numbers refer to the eye pieces and objective of the microscope employed, — an Obechauser in the possession of my friend and pupil, Mr. John Dean, to whom I am indebted for these figures.

was so nearly closed by accretions throughout its entire length, that it was removed because it ceased to serve water.

"I now return to the inquiry, How far these accretions extend?

"The inquiries and personal inspection of the Engineer and President of the Water Board, made in New York, Philadelphia and Baltimore, the fruits of which have been kindly placed at my disposal, have shown: —

"1st. That similar accretions occur in the iron mains of all the above named Cities.

"2d. That in Philadelphia, the accretions, now after a lapse of thirty-seven years, are too inconsiderable to be the occasion of any present or future solicitude.

"3d. That those in Baltimore and New York, though somewhat more extensive than in Philadelphia, are still so much inferior in size and number, especially when we compare the three years' service of the Cochituate Water with the ten of New York, and the still longer period of Baltimore, that the indefinitely long prospect of unobstructed distribution in New York and Baltimore, based upon their experience so far, does not throw the desired light upon the future of the Cochituate iron mains.

"One fact, of particular moment in this connection, has come to my knowledge. A gentleman of my acquaintance, accustomed to careful observation, remarked on a visit to Versailles, sections of iron mains of a foot in diameter, more than half filled with this kind of accretion. I hope soon to hear more particularly in regard to the attendant circumstances of this case, and also to learn more of the experience of the old world in the use of iron mains.

"The solicitude lies in two directions. In the first place, the accretions diminish the serving capacity. Taking the present average thickness of the incrustation at three-eighths of an inch, the serving capacity of a pipe 36 inches in diameter is reduced by the amount of an area of 42$\frac{3}{4}$ square inches, which is equal to a cylindrical pipe 7.3 inches in diameter. If we conceive the accretion to go uniformly forward at this rate of 14$\frac{1}{4}$ square inches per annum, it would become a matter of immediate grave consideration. In the second place: the accretions are formed at the expense of the iron upon which they rest. With their increased thickness will come at a remote period, diminished strength of the iron.

"I understand there are but few cast-iron pipes in the city distribution, of less than six inches calibre. It may be that the more rapid flow in these generally, will impede the growth of the accretions. It may be that after the accretions shall have coated the whole interior of the pipes, and attained a certain moderate thickness, their further growth will be much slower, if not altogether arrested.

"With my present knowledge, I do not feel prepared to say that there is any substantial ground of alarm in view of the incrustations upon the iron mains. At the same time, I cannot affirm that there may not be some reasonable solicitude, and I shall not fail to make myself acquainted with the subject, as the illustration goes daily forward before us, as well as with what has been elsewhere observed in the same field.

I am very respectfully,

Your obedient servant,

E. N. Horsford."

SECOND REPORT OF PROFESSOR HORSFORD.

"CAMBRIDGE, January 10th, 1853.

"THOMAS WETMORE, Esq.,
President of the Cochituate Water Board.

"Dear Sir,— Since the date of my former letter to you, I have been enabled, through the co-operation of the City Engineer, to assure myself of the steady growth of the accretions in the Cochituate iron mains. Plaster casts, taken in various localities and after unequal times from the laying down of the pipes, exhibit, in the relative sizes of the nodules, satisfactory evidence upon this point.

"Some consideration has been bestowed upon the various agencies that have been suggested, as operating to promote the growth of the accretions. Of these, a prominent one has been the presence of inorganic salts in the water.

"It might be presumed, that the surface-water of a region of country which is from time to time visited by rains, during the prevalence of a strong wind from the sea, would contain more or less of the ingredients of sea-water. The rain-water, falling at Paris and at all points to the eastward as far as Frankfort on the Main, gives the reactions of common salt. Farther east, at Munich, rain-water does not show these reactions. The chloride of sodium and the other saline matters of the ocean, brought by east winds over the basin drained by Cochituate lake, would, on being precipitated by rainfalls, confer on the water, it is conceived, power to act upon the iron pipes. But if we unite what comes from this source with what is supplied from the soil, both together leave the Cochituate so remarkably pure that rain-water is scarcely to be preferred for any purposes whatever; and its effect on iron pipes from this cause must be quite inappreciable. When we compare its action with that of the Croton and Schuylkill waters, we ought to find the accretions in number and size proportionate, in some degree, to the amount of salts the waters severally contain. These are as follows: —

	In one hundred thousand parts.		
	Croton.	Schuylkill.	Cochituate.
"Solid residue	18.71	9.42	5.35
Inorganic	11.34	7.29	2.90
Organic	7.37	2.13	2.45

"According to this table, and the view above expressed, we should find the accretions, in magnitude and number, in the order of Croton, Schuylkill and Cochituate.

"In reality, no regard is paid to this succession. Facts give Cochituate the first rank, and Schuylkill the last.

"The above quantities do not, however, represent the relative amounts of Chlorides, which are the more efficient salts in promoting the accretions. These are contained in the following proportions: — (Silliman's Report to Water Commissioners.)

	Croton.	Schuylkill.	Cochituate.
"Chloride of Sodium	0.167	0.147	0.032
Chloride of Potassium	trace	....	0.038
Chloride of Calcium	0.153	....	0.031
Chloride of Magnesium	.....	0.009	0.076
Chloride of Aluminium	0.372	....	....
Total	0.692	0.156	0.177

"According to this table, the Croton should stand first, and the Cochituate occupy an intermediate rank.

"The most striking peculiarity of the Cochituate water is, as already mentioned, its remarkable purity and, of course, its superior capacity for holding air in solution. From the well-known joint action of air and water in rusting iron, this characteristic may fairly be entitled to a share of influence in promoting the accretions. That it is not the only or the most prominent cause, will be apparent from the following considerations:

"1. Among the results of experiments by Meyer (J. Tech. Chem. X. 833) are the following: — The rusting is impaired by the smoothness of the surface, by hardness, by the contact of zinc, and by the presence of carbon as in cast-iron. It is promoted by roughness, by purity of the metal, and by the presence of sulphur. Payen (Ann. Chem. Phys. L. 305,) confirmed by experiments the observations of Wetzlar, that alkaline waters protect the iron. By neutralizing any acid the waters might contain, and thus preventing the first coat of oxide from going into solution, it leaves the iron protected by a shield of its own rust. This author also found, that the gray variety of cast-iron oxidated more readily than the white. (Ann. Chem. Phys. LXIII. 405.) These observations have been confirmed by researches undertaken by the British Association, which have, I know, fallen under your notice.

"2. It was observed in taking casts of the nodules, that areas of many square inches and in some instances, of several square feet, were free from accretions, while immediately around, they were found in great profusion. In some sections of pipe, only large nodules had taken root, and these were quite uniformly distributed. In others, those only of lesser size were found, and they were quite closely arranged.

"3. In situations, where other metals could exercise influence, the nodules had been most manifestly governed in their position and number by the proximity of the other metals. This was especially apparent in the well-defined disk of accretions on the plain iron surface, opposite the large composition circular valves of the mains, which were taken out for repairs in the course of last year and the year previous.

"It is manifest from the above considerations, that there has been galvanic action, arising in one class of cases, from the contact of metals of unlike affinity for oxygen, and generally from a want of homogeneity of the iron, and I feel strongly induced to coincide in the opinion that to this, more than to any other agency is to be ascribed the rapid formation of accretions in the Cochituate iron mains. It might be worth while to see how far this view, which has been arrived at, as well from observations in the old world, as with us, will be sustained by a comparison of analyses of fair sample specimens of the iron from the mains of Philadelphia, New York and Boston, and this I hope to lay before you in the course of the coming summer.

"I regret that my health has been such during the last twelve months, as to prevent the more extended investigation of this whole subject of accretions upon iron mains for the service of water, which I had projected last year. I regret this the less, however, since learning that you have become possessed of the ablest researches that have been made in this field; for I feel that, however industriously I might have pursued the matter in developing the influence of local peculiarities, I could scarcely have hoped to add to the practical information already in possession of your office.

I am, very respectfully,

Your obedient servant,

E. N. Horsford."

The Angus Smith coal-tar coating came into general use for cast-iron water pipes within a few years after these reports were made, and it proved so effective in preventing the formation of tubercles that we find comparatively little reference to it in later reports. After a time, however, it came to be recognized, at least in certain localities where the waters were soft, that old pipes would eventually become partly tuberculated and that their carrying capacity would then be reduced. It seems probable that in the early years the quality of the coating was better than that now obtainable. At any rate, the quantity of coal tar available was much greater in proportion to the amount of pipe produced, and the process of coating was not accelerated to the extent that is now common.

Interesting information regarding tuberculation and organic growths in cast-iron pipes laid in 1887 and 1894 is contained in the following report, never before published. It was made by Frederick S. Hollis, biologist of the Boston Water Works, to Desmond FitzGerald, then Superintendent of the Western Division.

"EXAMINATION OF THE 30- AND 36-INCH PIPES RECENTLY OPENED AT THE YARD OF THE CHESTNUT HILL RESERVOIR."

The 30-inch Pipe.

"The 30-inch pipe was laid in 1887 and has been in regular use. The examination was made on December 27, just after breaking the first joint. The white lead numbers on the inside of the end of the pipe were still clear. Brown slime and tubercles were present, each rather in patches. The tubercles varied in size, some of the largest ones measuring an inch or more in diameter.

Examination of the Slime.

"The slime consisted largely of collections of partly decomposed organic matter such as constitutes the amorphous matter reported as present in samples of water. It differed, however, in being uniformly discolored by the presence of iron.

"*Crenothrix* was present, but not in very large quantities, and many of the filaments showed but a slight sheath of rust.

"The diatoms observed were mainly such as are at present abundant in the water, and many of them were in a fresh condition.

"The infusorian *Acineta*, which is commonly found in connection with growths in pipes, was the most abundant organism present. It was found growing attached to most of the larger pieces composing the slime. — Among the rotifers *Polyarthra*, *Anuræa*, and *Rotifer vulgaris* were observed.

"Several species of worms were present, the most abundant being *Anguillula*, some of which were a millimeter or more in length. Pieces of the sheath of *Fredericella*, which is also characteristic of growths in pipes, were observed.

The 36-inch Pipe.

"The 36-inch pipe was laid in 1894. Two lengths of this pipe were removed on December 23. When examined, the scum originally present had dried and separated from the pipe, which showed an even and clean tarred surface except where tuberculation had developed. The only

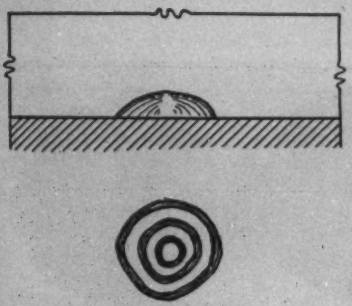


Fig 1.

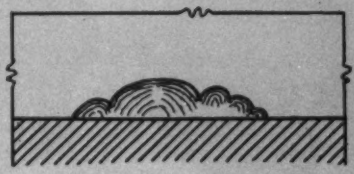


Fig 2.

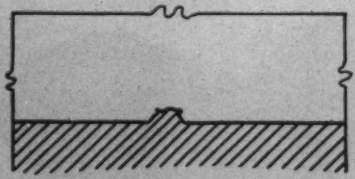


Fig 3.

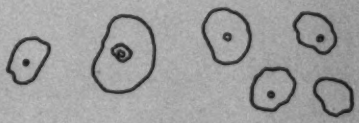


Fig 4.

examination of the organic growths that could be made in the case of this pipe was of the forms which adhered after drying. These consisted of the *Fredericella*, — the sheaths of which were quite abundant and evenly distributed, and the fresh water sponge (*Meyenia fluviatilis*) such as is found in Lake Cochituate.

"The sponge was present to perhaps the extent of ½ square inch to each square foot of surface.

The Tuberculation.

"The tubercles were similar in appearance in each pipe, but were considerably larger in the 30-inch or older pipe, in which some were found from 1 to 1¼ inch in diameter. Most of those in the 36-inch or newer pipe were small, varying from points to the larger ones which averaged ⅜ to ½ inch in diameter.

"In one section of the 36-inch pipe these were seen to follow straight lines which ran for about a third of the length of the section, and seemed to follow slight ridges in the casting. The tubercles from each pipe were seen to consist of a series of hemispherical shells not radiating or raying from a point, but overlapping each other so that at the base they appeared as a series of circles of increasing diameter arranged about a common center. (Fig. 1.)

"Generally the space between these hemispheres was filled with rust which held them together, but which was more easily removed by brushing than the material of the hemispheres, leaving the circular bases of these in relief. A few were found which consisted of only a hemispherical shell like a bubble. In the case of the larger ones the top surface showed numerous small rounded surfaces in addition to the main hemisphere, giving a botryoidal surface. (Fig. 2.)

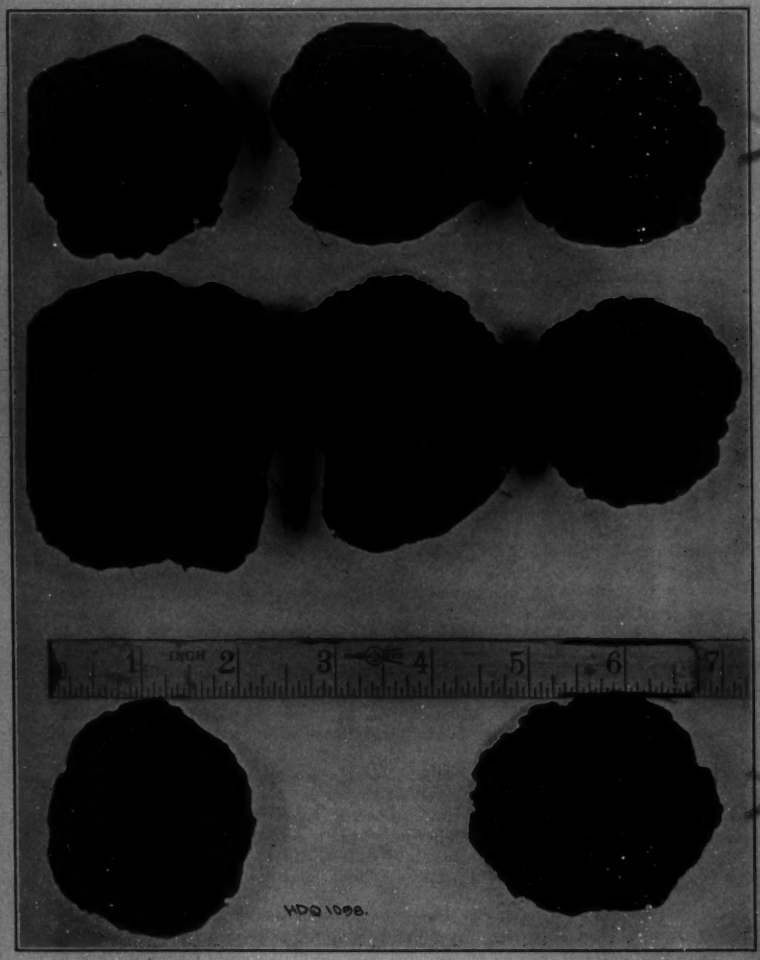


FIG. 5. — TUBERCLES TAKEN FROM 48-in. CAST-IRON PIPE AT ENTRANCE TO HIGH HILL RESERVOIR, MAY 1913. REAR VIEW.

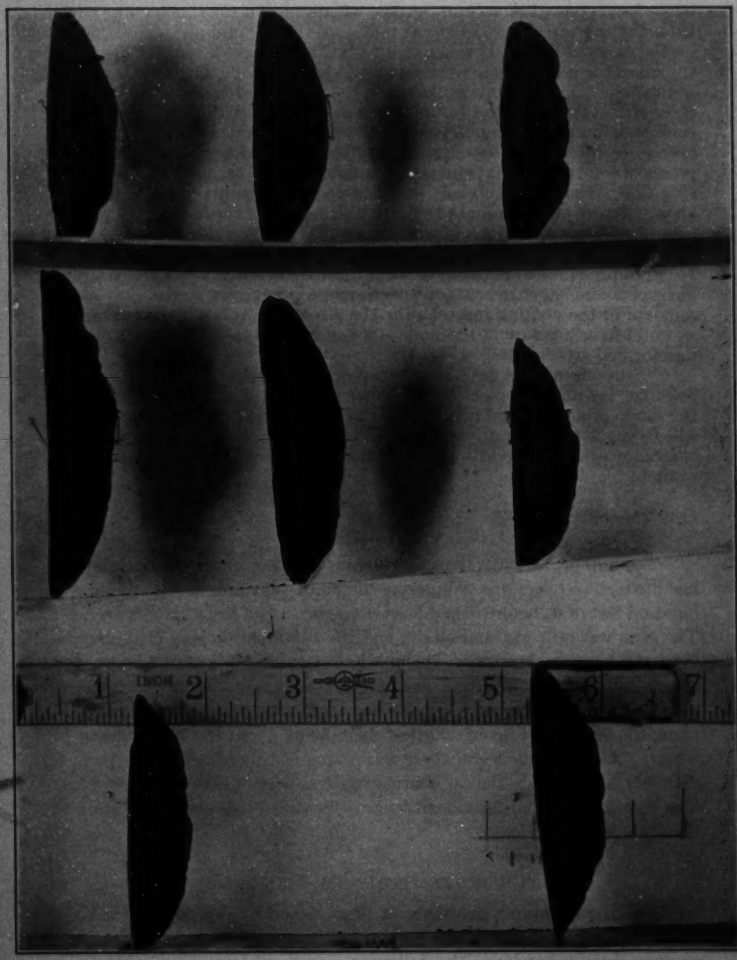


FIG. 6. — TUBERCLES TAKEN FROM 48-IN. CAST-IRON PIPE AT ENTRANCE TO HIGH HILL RESERVOIR, MAY 1913. SIDE VIEW.

"The tubercles generally scaled off from the tar coating and showed an almost glassy surface at the base. Some tar was found adhering to some of the larger ones, taken from the pipe when wet, but the smaller ones taken from the dry pipe have, as far as they have been examined, shown no tar on the exposed base. It was noticed that in the case of some of the larger tubercles the hemispheres were arranged about a projecting point or nodule in the pipe. These points appeared to the eye, after removing the tubercle, to be still coated with tar, but on cutting into some of them the iron was in each case found to be much nearer the surface than where the coating was even. In the case of the largest tubercle examined there were two sharp points of iron, projecting from such a nodule, which were probably uncoated. (Fig. 3.) When each tubercle was removed, whether about a nodule or on an apparently even tar coated surface, the outline of the largest hemisphere or outer ring of the tubercle was marked by a very slight removal of the tar coating, and this removal seemed to extend under the entire tubercle.

"Impressions were taken of six of these by rubbing a soft pencil over a piece of tissue paper in contact with the pipe. In this way the limit of the removal of the coating representing the size of the tubercle, was obtained, as well as the position of the nodule or nucleus in cases where the tubercle had formed around one. (Fig. 4.)

"Sections will be cut through the center of some of the tubercles, if possible, for microscopical examination in order to study more carefully the mode of growth and arrangement of the hemispheres, and an attempt will be made to ascertain whether the tar coating or other organic matter enters into their composition or whether they are simply forms of growth of rust.

(Signed) F. S. Hollis.

Dec. 28, 1897."

The author, who was then an assistant engineer under Mr. FitzGerald, has distinct recollections of entering the 36-in. pipe and inspecting several hundred feet of it, before it had been cut as described in Dr. Hollis's report. The pipe was still wet and slimy, and the examination was made by the light of a kerosene lantern. The pipe had been in service but 3 years, and the amount of tuberculation was not great. In places the surface felt roughly granular, and there were rather distinct lines of incipient tubercles along the crown and invert, most of them being about the size of grains of wheat. At each spigot end there was a ring of tubercles perhaps ¼-in. in diameter. Obviously the tar coating was less perfect here than elsewhere. The brown slimy coating was afterwards identified as consisting mainly of the organism *Fredericella*.

TUBERCLES FROM NEW BEDFORD.

The accompanying photographs (Figs. 5 and 6), reproduced from the 1913 report of the New Bedford Water Board, are excellent illustrations of characteristic tubercles. The following paragraphs are abstracted from the same report:

"In the cast-iron pipe, the tubercles themselves have grown considerably in size. The extent of this growth is best indicated by the four

outer rings, which can be clearly seen on photographs, showing the under or contact side of tubercle. Photographs showing the top and side view of sample tubercles from the cast-iron pipe are also submitted. (Figs. 5 and 6.)

"Samples of tubercles from the cast-iron pipe which enters the High Hill reservoir gate-house were collected, and analyses of the soft central or middle portion thereof and of the tubercles as a whole were made. Results of these analyses are as follows:

Analyses of Tubercles.

Sample marked No. 3, soft central portion of tubercles from 48-in. cast-iron pipe which enters High Hill Reservoir gate-house.

	Per cent.
Silica and insoluble matter	3.24
Ferric oxide, Fe_2O_3	69.12
Alumina & Lime, Al_2O_3 & CaO	traces
Sulphuric anhydride, SO_3	1.36
Water of hydration, H_2O	26.28
Carbon dioxide, CO_2	none

Sample marked No. 4, whole tubercle from 48-in. cast-iron pipe-line as above.

	Per cent.
Silica and insoluble matter	1.78
Ferric Oxide, Fe_2O_3	68.62
Alumina & Lime, Al_2O_3 & CaO	traces
Sulphuric anhydride, SO_3	.55
Water of hydration, H_2O	28.16
Carbon dioxide, CO_2	none

THE RAINFALL OF NEW ENGLAND.

Part II. Seasonal Rainfall.*

BY J. HENRY WEBER.†

Seasonal Distribution of Rainfall.

The New England region has a remarkably even seasonal distribution of rainfall. (Figs. 1–4.) There are, however, considerable differences within the bounds of the New England States, particularly between the coastal rain-gaging stations and those of the interior. All stations on the southern Massachusetts coast with its adjoining islands and those on the coast of Connecticut, Rhode Island and Maine indicate a winter maximum and a summer minimum of rainfall; in the far interior the maximum comes in summer and the minimum in winter or spring. This is in accord with the seasons of maximum and minimum rainfall in marine and continental climates. Between the coast and the far interior is the region of practically uniform mean monthly rainfall, some stations having less than a ½-in. annual range. Examples of these three types are: (1) *coastal region* — Bar Harbor, Me., with means of 5.1 and 3.1 in. in March and June, respectively; (2) *far interior region* — Burlington, Vt., with means of 1.63 and 3.60 in. in February and June, respectively; (3) *intermediate region* — Waltham, Mass., highest mean, 3.76 in., in September and the least 3.33 in., in June.

In the coastal stations the months of December, January, February and March have rather uniform rainfalls, although the tendency is towards slightly higher rainfall in January and March. From April to July, the amount diminishes steadily, while in July and August there is a reaction to slightly higher rainfall, due mainly to the increasing activity of convectional storms and the added influence of West Indian hurricanes. September has a lower rainfall than either July or August and, in some cases, one as low as, or lower than, June. This is the transition period between the great activity of convectional storms and that of the extra-tropical "lows." The influence of West Indian hurricanes on the rainfall of this region in September is also less than during either the preceding or following months. Rainfall due to hurricanes was tabulated from the daily weather maps, 1904–1926, for Eastport, Portland, Boston, Block Island and Nantucket. The results indicate that this influence accounts for 4 to 5 per cent. of the annual rainfall at these stations and that the greatest proportion of this rainfall comes in August and October.

The topography of New England is shown in Fig. 5, a relief map of the New England States and adjoining regions.

*Editor's Note: This is the second of the series of four papers by J. Henry Weber on "The Rainfall of New England."

†Clark University, Worcester, Mass.

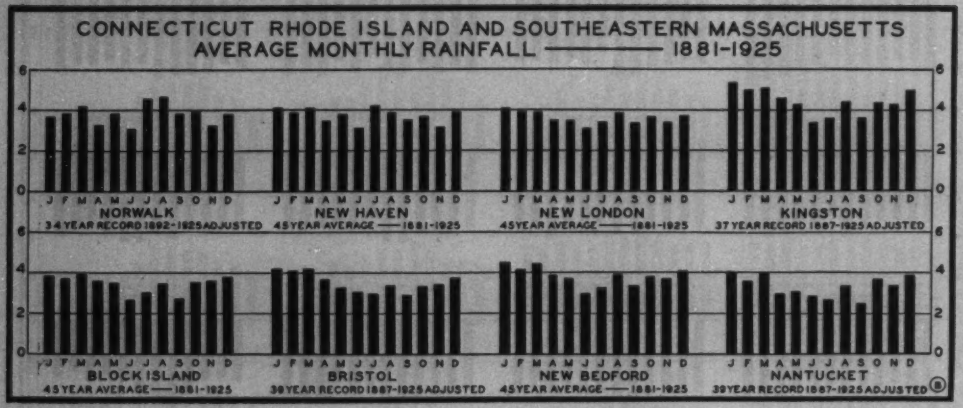

CONNECTICUT RHODE ISLAND AND SOUTHEASTERN MASSACHUSETTS
AVERAGE MONTHLY RAINFALL ——— 1881-1925
J F M A M J J A S O N D
NORWALK
34 YEAR RECORD 1892-1925 ADJUSTED
NEW HAVEN
45 YEAR AVERAGE — 1881-1925
NEW LONDON
45 YEAR AVERAGE — 1881-1925
KINGSTON
37 YEAR RECORD 1887-1925 ADJUSTED
BLOCK ISLAND
45 YEAR AVERAGE — 1881-1925
BRISTOL
39 YEAR RECORD 1887-1925 ADJUSTED
NEW BEDFORD
45 YEAR AVERAGE — 1881-1925
NANTUCKET
39 YEAR RECORD 1887-1925 ADJUSTED
0
2
4
6

Fig. 1.

THE RAINFALL OF NEW ENGLAND.

Part II. Seasonal Rainfall.*

BY J. HENRY WEBER.†

Seasonal Distribution of Rainfall.

The New England region has a remarkably even seasonal distribution of rainfall. (Figs. 1–4.) There are, however, considerable differences within the bounds of the New England States, particularly between the coastal rain-gaging stations and those of the interior. All stations on the southern Massachusetts coast with its adjoining islands and those on the coast of Connecticut, Rhode Island and Maine indicate a winter maximum and a summer minimum of rainfall; in the far interior the maximum comes in summer and the minimum in winter or spring. This is in accord with the seasons of maximum and minimum rainfall in marine and continental climates. Between the coast and the far interior is the region of practically uniform mean monthly rainfall, some stations having less than a ½-in. annual range. Examples of these three types are: (1) *coastal region* — Bar Harbor, Me., with means of 5.1 and 3.1 in. in March and June, respectively; (2) *far interior region* — Burlington, Vt., with means of 1.63 and 3.60 in. in February and June, respectively; (3) *intermediate region* — Waltham, Mass., highest mean, 3.76 in., in September and the least 3.33 in., in June.

In the coastal stations the months of December, January, February and March have rather uniform rainfalls, although the tendency is towards slightly higher rainfall in January and March. From April to July, the amount diminishes steadily, while in July and August there is a reaction to slightly higher rainfall, due mainly to the increasing activity of convectional storms and the added influence of West Indian hurricanes. September has a lower rainfall than either July or August and, in some cases, one as low as, or lower than, June. This is the transition period between the great activity of convectional storms and that of the extra-tropical "lows." The influence of West Indian hurricanes on the rainfall of this region in September is also less than during either the preceding or following months. Rainfall due to hurricanes was tabulated from the daily weather maps, 1904–1926, for Eastport, Portland, Boston, Block Island and Nantucket. The results indicate that this influence accounts for 4 to 5 per cent. of the annual rainfall at these stations and that the greatest proportion of this rainfall comes in August and October.

The topography of New England is shown in Fig. 5, a relief map of the New England States and adjoining regions.

*Editor's Note: This is the second of the series of four papers by J. Henry Weber on "The Rainfall of New England."

†Clark University, Worcester, Mass.

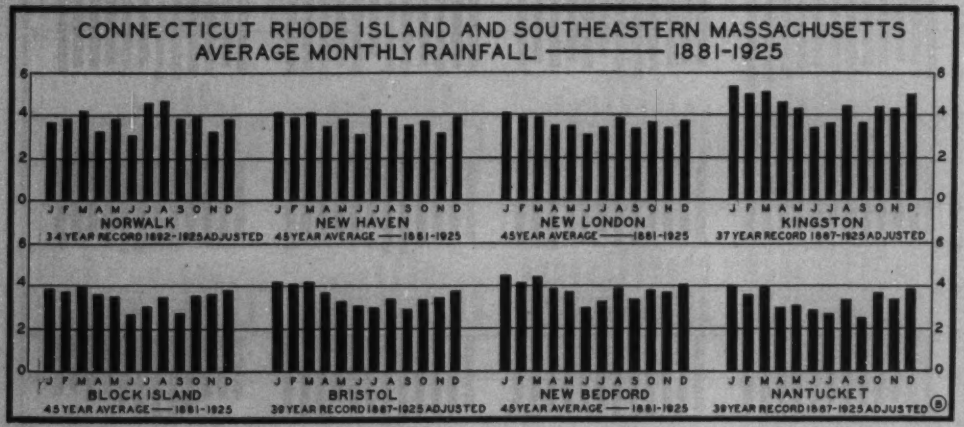

CONNECTICUT RHODE ISLAND AND SOUTHEASTERN MASSACHUSETTS
AVERAGE MONTHLY RAINFALL ——— 1881-1925
J F M A M J J A S O N D
NORWALK
34 YEAR RECORD 1892-1925 ADJUSTED
NEW HAVEN
45 YEAR AVERAGE —— 1881-1925
NEW LONDON
45 YEAR AVERAGE —— 1881-1925
KINGSTON
37 YEAR RECORD 1887-1925 ADJUSTED
BLOCK ISLAND
45 YEAR AVERAGE —— 1881-1925
BRISTOL
39 YEAR RECORD 1887-1925 ADJUSTED
NEW BEDFORD
45 YEAR AVERAGE —— 1881-1925
NANTUCKET
39 YEAR RECORD 1887-1925 ADJUSTED
0
2
4
6

Fig. 1.

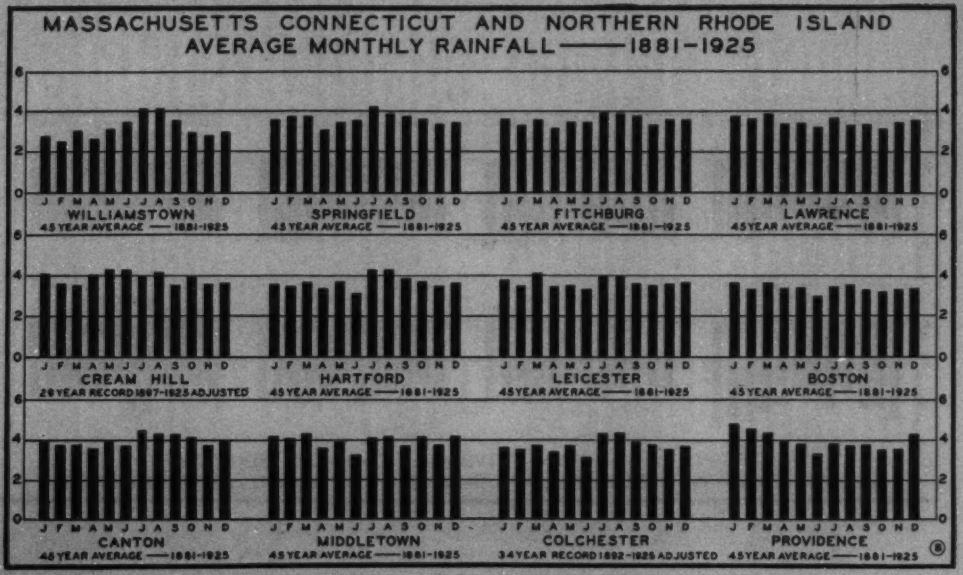

MASSACHUSETTS CONNECTICUT AND NORTHERN RHODE ISLAND
AVERAGE MONTHLY RAINFALL——1881-1925
J F M A M J J A S O N D
WILLIAMSTOWN
45 YEAR AVERAGE —— 1881-1925
SPRINGFIELD
45 YEAR AVERAGE —— 1881-1925
FITCHBURG
45 YEAR AVERAGE —— 1881-1925
LAWRENCE
45 YEAR AVERAGE —— 1881-1925
CREAM HILL
28 YEAR RECORD 1897-1925 ADJUSTED
HARTFORD
45 YEAR AVERAGE —— 1881-1925
LEICESTER
45 YEAR AVERAGE —— 1881-1925
BOSTON
45 YEAR AVERAGE —— 1881-1925
CANTON
45 YEAR AVERAGE —— 1881-1925
MIDDLETOWN
45 YEAR AVERAGE —— 1881-1925
COLCHESTER
34 YEAR RECORD 1892-1925 ADJUSTED
PROVIDENCE
45 YEAR AVERAGE —— 1881-1925

FIG. 2.

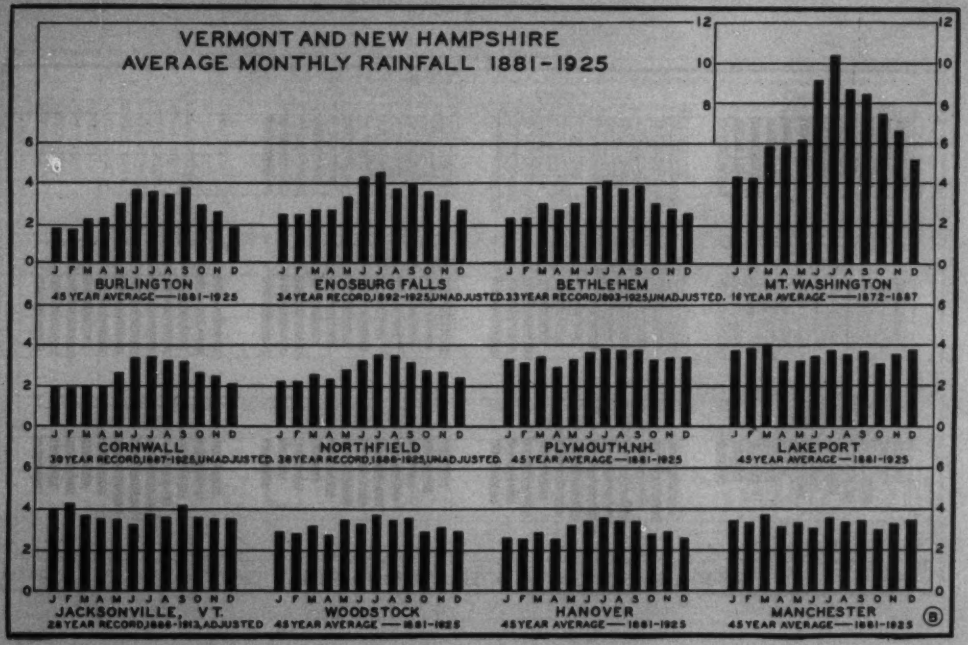

VERMONT AND NEW HAMPSHIRE
AVERAGE MONTHLY RAINFALL 1881-1925
BURLINGTON
45 YEAR AVERAGE — 1881-1925
ENOSBURG FALLS
34 YEAR RECORD, 1892-1925, UNADJUSTED.
BETHLEHEM
33 YEAR RECORD, 1893-1925, UNADJUSTED.
MT. WASHINGTON
16 YEAR AVERAGE — 1872-1887
CORNWALL
39 YEAR RECORD, 1887-1925, UNADJUSTED.
NORTHFIELD
38 YEAR RECORD, 1886-1925, UNADJUSTED.
PLYMOUTH, N.H.
45 YEAR AVERAGE — 1881-1925
LAKEPORT
45 YEAR AVERAGE — 1881-1925
JACKSONVILLE, VT.
28 YEAR RECORD, 1886-1913, ADJUSTED.
WOODSTOCK
45 YEAR AVERAGE — 1881-1925
HANOVER
45 YEAR AVERAGE — 1881-1925
MANCHESTER
45 YEAR AVERAGE — 1881-1925
J F M A M J J A S O N D
0
2
4
6
8
10
12

FIG. 3.

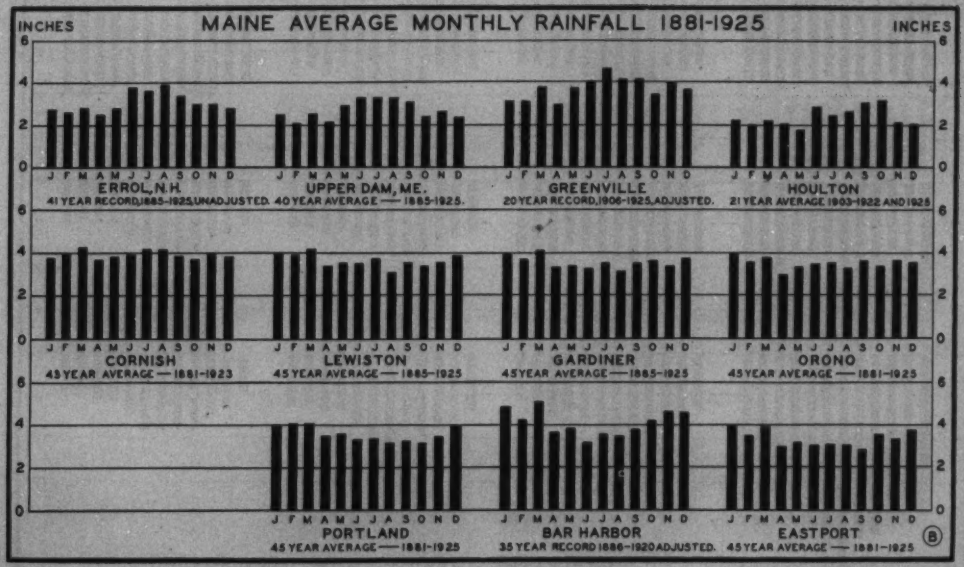

MAINE AVERAGE MONTHLY RAINFALL 1881-1925
INCHES
INCHES
J F M A M J J A S O N D
ERROL, N.H.
41 YEAR RECORD, 1885-1925, UNADJUSTED.
UPPER DAM, ME.
40 YEAR AVERAGE — 1885-1925.
GREENVILLE
20 YEAR RECORD, 1906-1925, ADJUSTED.
HOULTON
21 YEAR AVERAGE 1903-1922 AND 1925
CORNISH
43 YEAR AVERAGE — 1881-1923
LEWISTON
45 YEAR AVERAGE — 1885-1925
GARDINER
45 YEAR AVERAGE — 1885-1925
ORONO
45 YEAR AVERAGE — 1881-1925
PORTLAND
45 YEAR AVERAGE — 1881-1925
BAR HARBOR
35 YEAR RECORD 1886-1920 ADJUSTED.
EASTPORT
45 YEAR AVERAGE — 1881-1925
B

Fig. 4.

FIG. 5.

MEAN SEASONAL RAINFALL (SOUTHERN NEW ENGLAND).

Winter Rainfall. The mean winter rainfall (Fig. 6) for most of southern New England amounts to between 10 and 13 in. A belt of higher rainfall, above 12 in., extends from western Connecticut northeastward to the

Massachusetts coast, reaching a maximum in southern Rhode Island where a small area is enclosed by the 14-in. isohyet. The southern portion of this region has higher mean winter temperatures and is in closer proximity than the northern area, to the main sources of moisture, namely the Gulf of Mexico and the Atlantic Ocean. Other things being equal, we should expect the highest rainfall here. A higher rainfall is indicated just back from the coast, particularly in Rhode Island; the factors instrumental in bringing about this condition have been explained in Part I.

About one-fourth to one-third of the winter precipitation in the southern area falls as snow.* This proportion increases towards the interior, being greatest in the higher elevations of the Berkshire Hills in northern Massachusetts, where snowfall accounts for by far the greater part of the winter precipitation. In the northern portion of the area, there are many small areas indicating values below 10 in. and a few above 12 in.

The greatest mean winter rainfall is 15.0 in. at Kingston, R. I., and the least, 8.2 in. at Williamstown, Mass.

Spring Rainfall. The mean spring rainfall (Fig. 7), again indicates a higher rainfall in the southern portion of the region although there is no continuous belt extending east and west, as was the case in the mean winter rainfall. The higher rainfall in the southern region is due chiefly to the greater precipitation in March. Areas of 12 in. or greater are confined mostly to the southern portion, while 10 in. or lower are found only in Massachusetts. The greatest spring rainfall is 13.7 in., at Kingston, R. I., and the least, 8.8 in., at Williamstown, Mass.

Summer Rainfall. In summer (Fig. 8) the rainfall distribution is nearly the reverse of that in winter and spring, the greatest rainfall occurring in the interior and the least on the coast. Nearly all of Massachusetts and Connecticut west of the Connecticut River, have a mean summer rainfall above 12 in., with a few small areas exceeding 14 in. The Narragansett Basin and most of the coastal region of Massachusetts have under 10 in., the southeastern portion being the most deficient. The mean values vary from 14.5 in. at Savoy in the Berkshire Hills of Massachusetts, to 8.3 in. at Provincetown, Mass.

Autumn Rainfall. The mean autumn rainfall (Fig. 9) is rather evenly distributed throughout the area, and for the region as a whole averages very close to 11 in. The coastal influence noted during the summer months still persists but to a less marked degree. The 10-in. isohyet encloses a lesser area in southeastern Massachusetts, than it does in the summer season, although in most of northeastern Massachusetts the values are somewhat lower than during the preceding season. The lowest mean value, however, is at Williamstown, 9.2 in.

*For a complete discussion of the geographical distribution of snowfall in this area, see C. F. Brooks's study of "New England Snowfall," *Monthly Weather Review*, 1917, Vol. 45, pp. 271–285, 30 figs.

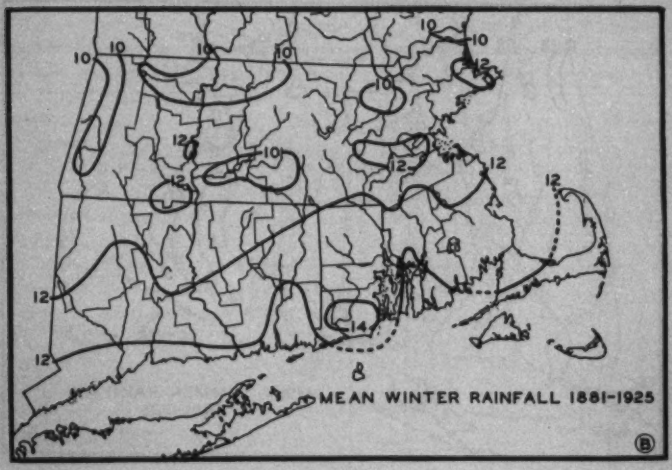

MEAN WINTER RAINFALL 1881-1925
B

FIG. 6.

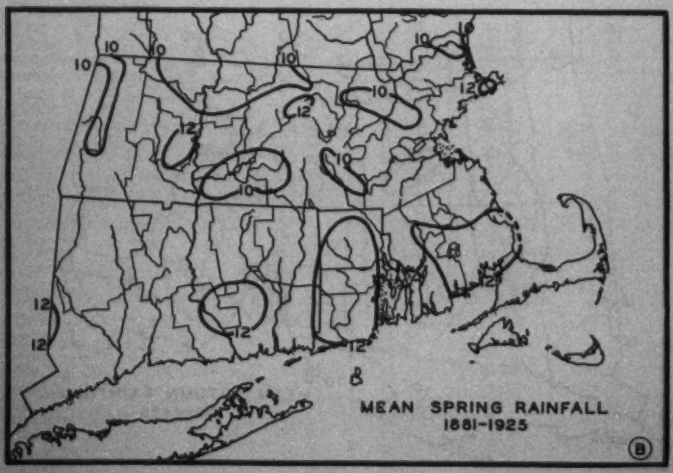

MEAN SPRING RAINFALL
1881-1925
B

FIG. 7.

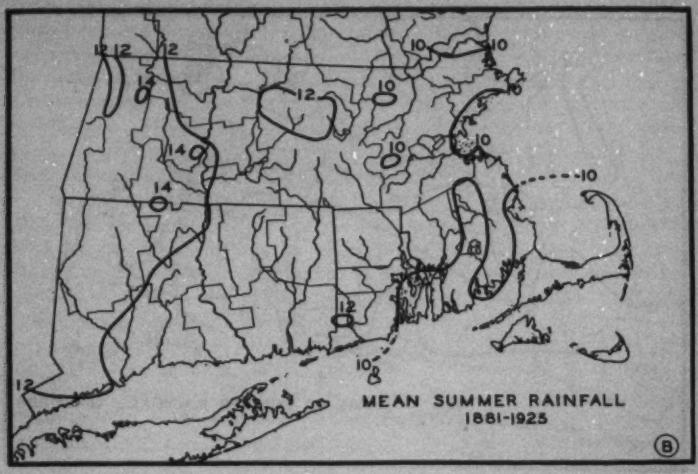

MEAN SUMMER RAINFALL
1881-1925
B

FIG. 8.

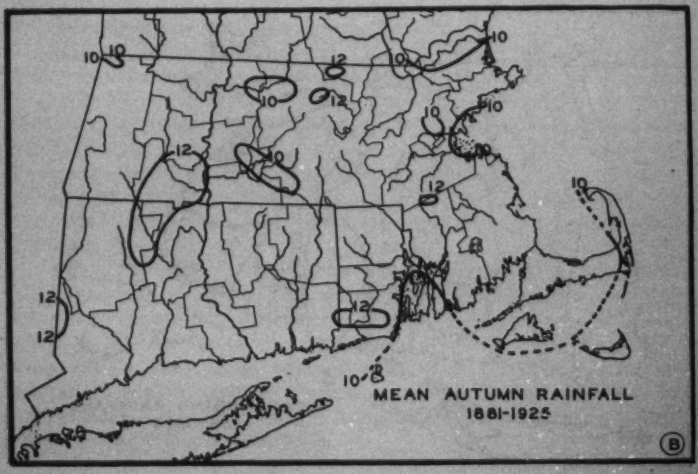

MEAN AUTUMN RAINFALL
1881-1925
B

FIG. 9.

Mean Seasonal Rainfall in Southern New England.

Massachusetts.

	Winter.	Spring.	Summer.	Autumn.
Acushnet	12.89	12.27	10.05	11.52
Agawam	12.1	12.1	12.7	12.1
Amherst	10.59	10.62	11.77	10.71
Ashby	10.4	11.9	11.8	12.4
Ashland	12.15	11.02	9.87	10.40
Athol	8.7	9.1	12.6	9.9
Attleborough	12.0	11.5	10.4	10.8
Bedford	10.2	9.5	10.2	9.7
Belchertown	10.4	10.1	11.2	9.7
Blue Hill (Summit)	11.99	11.47	11.24	11.53
Blue Hill (Valley)	11.6	11.1	10.6	11.1
Boston	10.15	10.19	9.65	9.54
Boylston	11.9	11.7	11.7	11.0
Bridgewater	12.1	11.6	10.6	10.7
Brockton	10.44	10.25	9.81	10.23
Cambridge	11.12	10.68	9.77	10.11
Chester	11.3	10.3	12.0	11.0
Chestnut Hill	12.29	11.34	10.66	10.96
Clinton	11.22	10.35	10.81	10.38
Colrain	10.5	11.0	11.7	11.1
Concord	10.3	10.1	10.4	10.1
Cotuit	11.1	10.7	9.2	11.1
Dalton	10.1	10.3	12.1	10.4
Danvers	10.1	11.2	9.8	10.5
Dudley	11.1	10.7	10.8	10.3
Easthampton	12.0	13.0	14.3	13.7
Egremont	10.0	10.2	12.6	10.5
Fall River	12.35	11.75	10.12	11.00
Fitchburg	10.34	10.05	11.07	10.42
Framingham	11.99	11.03	10.23	10.58
Gardner	11.4	11.5	11.7	10.9
Gloucester	12.7	12.4	10.7	11.3
Granville (a)	11.0	11.1	13.2	12.1
Granville (b)	13.5	13.0	12.8	13.3
Groton	10.4	10.6	10.4	10.6
Haverhill	10.4	10.4	9.8	9.9
Hingham	11.80	11.02	10.84	11.36
Holden	11.12	11.14	11.46	11.28
Holyoke	11.4	11.7	12.7	11.3
Hyannis	11.9	11.65	9.7	10.25
Ipswich	12.35	12.15	10.4	11.0
Lakeville	12.41	12.02	10.02	10.87
Lawrence	10.80	10.53	10.18	9.79
Leeds	11.94	12.00	12.41	11.30
Leicester	10.74	11.04	11.20	10.65
Leominster	10.56	10.64	11.42	10.75
Lincoln	8.9	9.9	10.3	9.9
Littleton	8.5	9.1	9.8	10.1
Lowell	11.64	11.17	10.58	10.39
Ludlow	9.70	10.04	11.62	10.08
Lynn	10.56	10.39	10.14	9.94
Manchester	11.1	11.0	9.7	10.8
Mansfield	13.2	11.65	11.75	12.0
Marlborough	10.3	10.2	10.3	10.7
Medford	10.9	10.6	10.2	10.2
Middleboro	12.3	11.1	9.9	10.6
Milford	10.6	10.0	10.2	10.3
Monroe Bridge	10.3	10.6	13.1	11.0

MEAN SEASONAL RAINFALL IN SOUTHERN NEW ENGLAND.

Massachusetts (Continued).

	Winter.	Spring.	Summer.	Autumn.
Monson	10.8	10.1	11.4	10.7
Nantucket	11.55	10.09	9.00	9.67
Natick	11.88	10.74	10.18	10.56
New Bedford	12.72	12.11	10.34	10.86
Newburyport	9.0	9.6	9.45	9.95
Newton	11.1	10.9	10.3	9.8
Norfolk	11.0	10.2	11.1	11.4
North Adams	10.2	10.0	12.7	10.5
North Andover	10.0	10.3	10.5	10.0
North Billerica	10.0	10.3	10.8	10.1
Northbridge	11.63	11.18	11.12	10.92
Norwood	10.2	10.3	11.6	10.5
Otis	10.3	10.7	13.3	11.2
Peabody	11.3	10.8	11.0	11.0
Pembroke	11.8	11.8	10.4	10.4
Peru	10.8	11.0	13.1	11.0
Petersham	10.5	9.75	13.3	11.45
Pittsfield	10.1	9.7	11.9	10.1
Plymouth	12.90	12.08	9.88	11.11
Prescott	10.4	11.0	12.7	11.1
Princeton	11.11	10.95	12.22	10.82
Provincetown	10.85	10.32	8.32	9.45
Quincy	10.9	10.2	11.3	10.8
Reading	11.0	10.8	10.5	10.5
Rochester	12.95	12.60	11.1	11.65
Rockport	11.4	10.8	10.3	10.6
Rowe	10.0	9.5	11.9	11.5
Rutland	10.1	11.0	12.3	10.9
Salem	10.6	10.6	9.8	10.1
Savoy	11.5	10.2	14.5	11.1
Sharon	12.1	10.8	10.8	10.4
Shelburne Falls	8.8	9.6	11.3	10.5
Somerset	11.87	11.74	10.07	10.65
Somerville	10.7	10.8	10.2	10.6
Southampton	11.4	12.0	12.7	12.2
Southboro	12.70	11.56	10.66	11.17
Southbridge	10.9	11.5	10.4	11.1
Springfield	10.42	9.94	11.60	10.55
Sterling	11.0	10.4	11.1	10.5
Stoneham	11.5	11.1	11.8	11.2
Taunton	13.21	12.20	10.78	11.48
Templeton	10.05	9.55	10.5	9.7
Turners Falls	9.5	9.8	10.4	10.8
Vineyard Haven	11.8	11.0	8.9	10.6
Walpole	10.8	10.3	10.5	10.1
Waltham	10.72	10.57	10.65	10.74
Wareham	12.5	12.5	10.0	10.5
Warren	9.4	9.8	11.5	9.9
Webster	11.19	10.79	10.67	10.19
Wellesley	11.7	11.4	10.9	10.8
Wenham	10.14	10.34	10.92	10.75
Westborough	11.30	10.96	10.83	10.88
West Brookfield	9.3	9.7	11.8	10.2
Westfield	12.7	11.5	13.0	12.3
West Granville	11.1	11.9	13.5	12.0
Westminster	12.2	12.6	12.1	12.5
Weston	11.4	10.9	10.6	10.5
Williamsburg	9.9	10.6	11.4	11.7

MEAN SEASONAL RAINFALL IN SOUTHERN NEW ENGLAND.

Massachusetts (Continued).

	Winter.	Spring.	Summer.	Autumn.
Williamstown	8.21	8.75	11.67	9.20
Winchendon	10.0	10.0	11.7	10.7
Winchester	10.6	9.6	9.9	9.9
Woods Hole	11.35	10.7	8.9	10.05
Worcester	10.16	10.04	10.31	10.37
Worthington	11.6	11.3	12.5	11.4

MEAN SEASONAL RAINFALL IN SOUTHERN NEW ENGLAND.

Connecticut.

	Winter.	Spring.	Summer.	Autumn.
Bridgeport	11.79	11.78	12.51	11.30
Burlington (a)	10.3	11.2	13.1	11.8
Burlington (b)	12.5	12.8	12.8	13.0
Canton	11.66	11.31	12.39	11.93
Colchester	13.3	12.8	11.7	11.7
Cream Hill	11.3	11.8	12.5	11.0
Danielson	12.3	10.6	10.8	11.3
Enfield	10.3	10.6	12.2	11.6
Fall Village	10.27	10.24	12.28	11.00
Greenwich	10.84	10.63	11.74	10.42
Hartford	10.66	10.55	11.65	11.04
Hartland	13.0	11.8	14.0	12.8
Lake Konomoc	12.7	12.0	10.3	10.9
Mansfield	11.3	10.9	11.5	10.5
Middletown	12.19	11.66	11.38	11.40
Nepaug	11.9	11.6	12.4	12.2
New Haven	11.83	11.29	11.30	10.45
New London	11.74	10.98	10.42	10.44
Newtown	12.0	11.8	11.9	11.4
No. Grosvenor Dale	11.9	11.2	10.9	10.4
Norwalk	11.35	11.32	12.73	11.08
Norwich	11.19	10.80	10.53	10.12
Simsbury	11.1	10.45	11.35	11.1
Southington	11.26	10.56	10.97	10.46
Voluntown	12.85	11.55	10.83	11.09
Wallingford	13.35	11.68	11.29	10.98
Waterbury	12.60	11.46	12.34	10.87

MEAN SEASONAL RAINFALL IN SOUTHERN NEW ENGLAND.

Rhode Island.

	Winter.	Spring.	Summer.	Autumn.
Block Island	11.29	11.00	9.13	9.79
Bristol	11.98	10.99	9.31	9.60
Cranston	13.65	12.25	10.3	11.3
Foster	12.9	12.5	11.3	11.7
Hope	13.35	12.30	11.05	11.62
Hopkinton	13.8	12.6	12.1	12.3
Kingston	15.04	13.70	11.25	12.15
Lonsdale	12.3	11.5	11.0	10.9
Narragansett Pier	12.56	12.47	10.29	10.91
Pawtucket	13.08	11.52	10.95	10.49
Providence	13.43	11.91	10.62	11.00
Scituate	12.4	11.8	11.1	10.9
South Scituate	12.75	12.1	11.8	11.35
Wallum Pond	11.1	10.7	11.7	11.2
Woonsocket	12.59	11.90	11.34	11.22

THE RAINFALL OF NEW ENGLAND.

PART III. MEAN MONTHLY RAINFALL OF SOUTHERN NEW ENGLAND.*

BY J. HENRY WEBER.†

The mean January rainfall (Fig. 1) is greatest in the southern portion, exceeding 5 in. in southern Rhode Island. The 4-in. isohyet encloses nearly all of Massachusetts south of a line from the vicinity of Boston to the east of Worcester, all of Rhode Island and the greater portion of Connecticut, exclusive of the north central portion. The southwestern coast of Connecticut and portions of Cape Cod have under 4 in. Williamstown, in the Hoosic Valley, and Shelburne Falls, in the Deerfield Valley, are the only areas having under 3 in. Kingston, R. I., with 5.21 in., has the highest mean value; this is also the highest mean monthly rainfall reported by any of the longer record stations in southern New England.

In February (Fig. 2) the general rainfall distribution is similar to that of January, although the area enclosed by the 4-in. isohyet is less. Along the entire Connecticut coast the rainfall is under 4 in., whereas in January only the southwestern portion experienced that condition. The 5-in. isohyet has disappeared from southern Rhode Island, although Kingston has 4.94 in. Given the same number of days as January, the 5-in. isohyet would appear here, as it did in January. Cape Cod and part of the Narragansett Basin, have under 4 in.

Williamstown, with a mean of 2.52 in., has the lowest February rainfall in the area; this is also the lowest mean monthly rainfall in southern New England.

The March mean rainfall (Fig. 3) is practically a duplicate of that of January, there being no differences worthy of note. December, January, February and March, are the months of greatest excess in the semi-marine conditions on the southern coast and the continental type in the interior.

April is the month of minimum mean rainfall (Fig. 4) for most of the northern portion; here the greater proportion of the stations have values between 3.0 and 3.5 in., while northwestern Massachusetts is the only area of any extent with amounts below 3 in. Nearly all of Rhode Island and smaller areas to the east and west have over 4 in. In April the snow cover to the north and the cold water bodies to the eastward favor the development and maintenance of a high pressure area over the northeast. This factor plus the decreasing activity of extra-tropical lows is instrumental in producing drier conditions than in the previous month, throughout the entire area.

*Editor's Note: This is the third of the series of four papers by J. Henry Weber on "The Rainfall of New England."

†Clark University, Worcester, Mass.

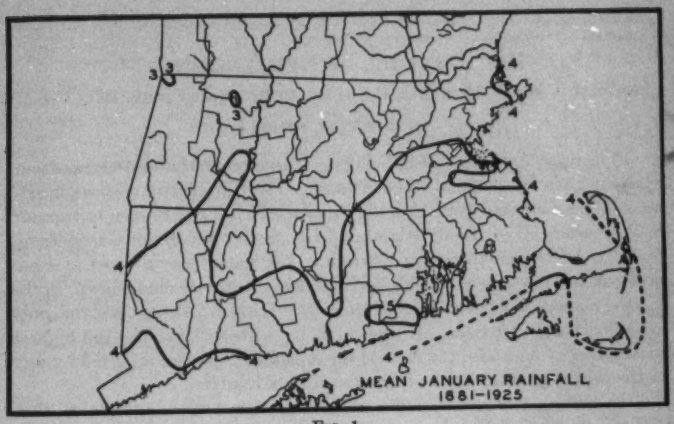

MEAN JANUARY RAINFALL
1881-1925

FIG. 1.

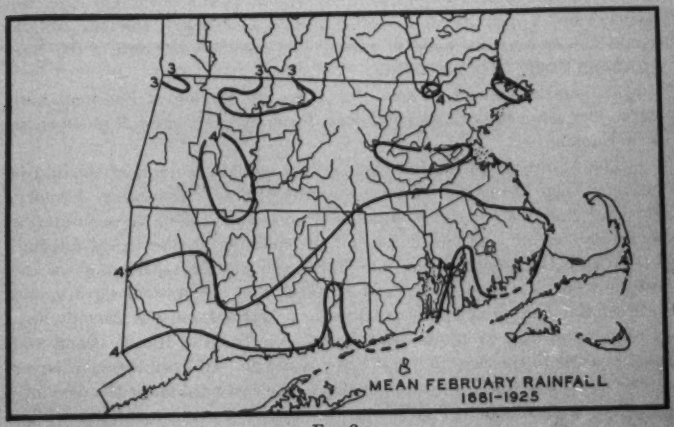

MEAN FEBRUARY RAINFALL
1881-1925

FIG. 2.

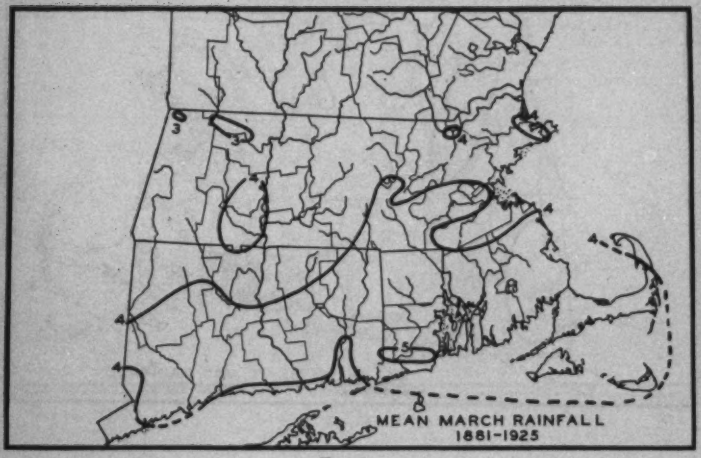

MEAN MARCH RAINFALL
1881-1925

FIG. 3.

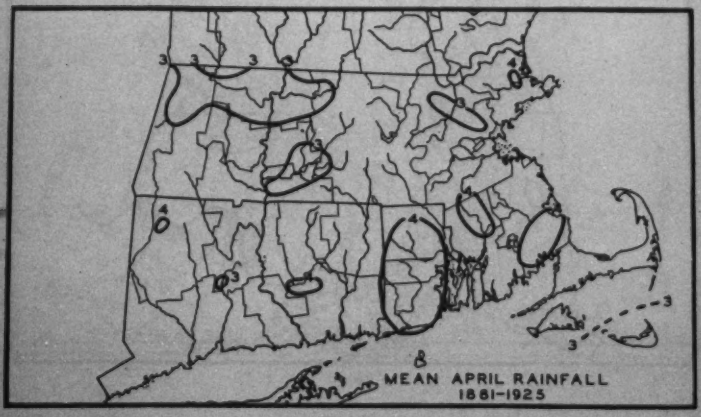
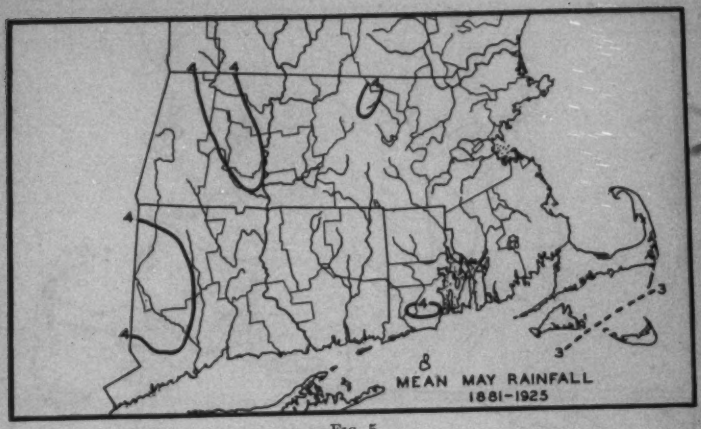

MEAN APRIL RAINFALL
1881-1925

FIG. 4.


4
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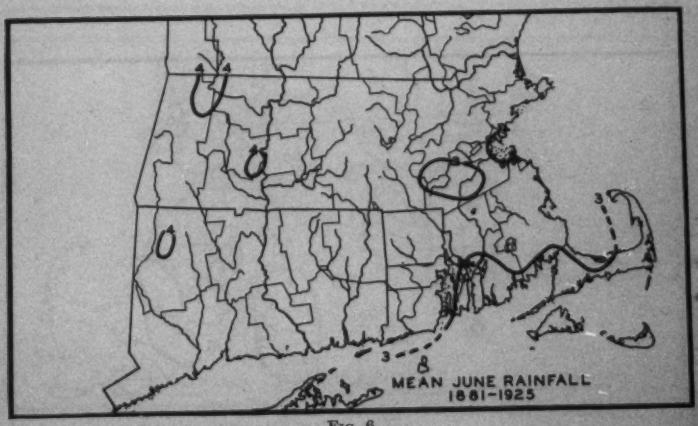
8
MEAN MAY RAINFALL
1881-1925

FIG. 5.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MEAN JUNE RAINFALL
1881-1925

FIG. 6.

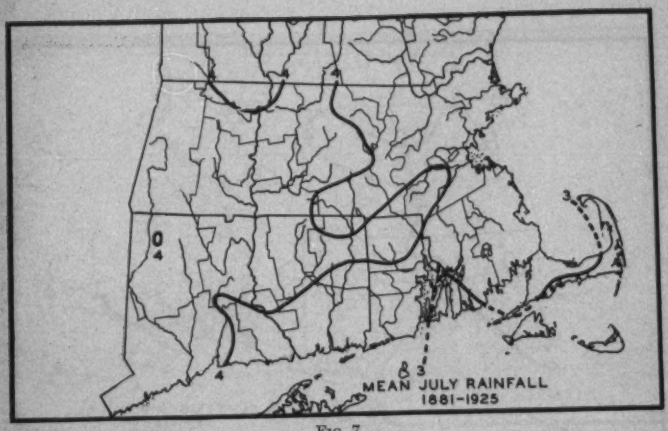

MEAN JULY RAINFALL
1881-1925

FIG. 7.

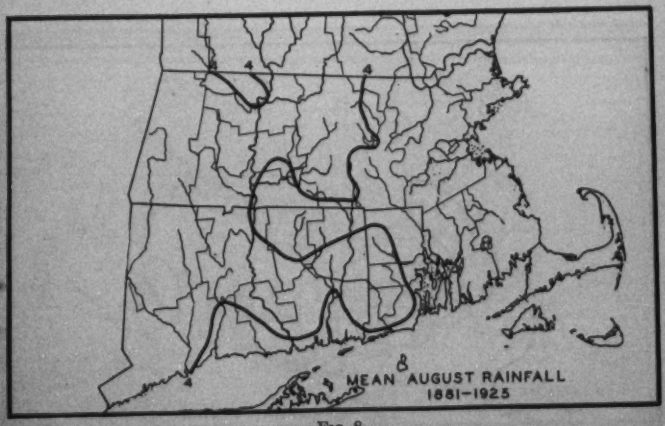

MEAN AUGUST RAINFALL
1881-1925

FIG. 8.

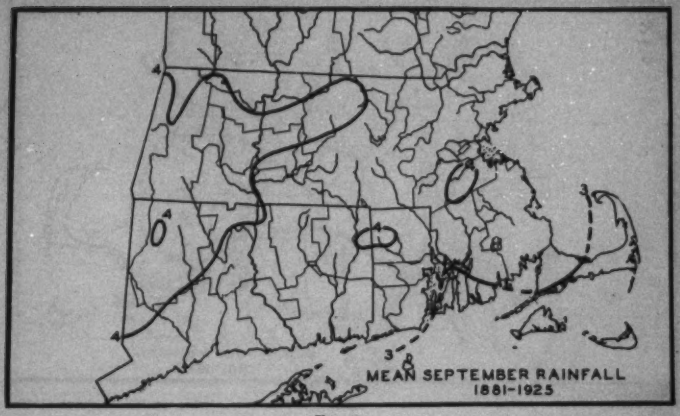

MEAN SEPTEMBER RAINFALL
1881-1925

FIG. 9.

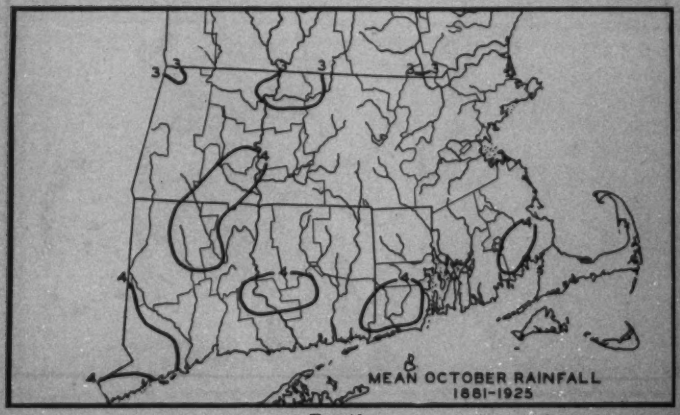
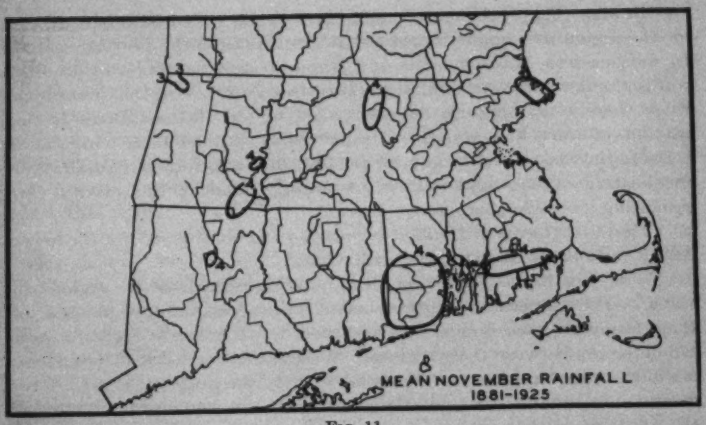

MEAN OCTOBER RAINFALL
1881-1925

FIG. 10.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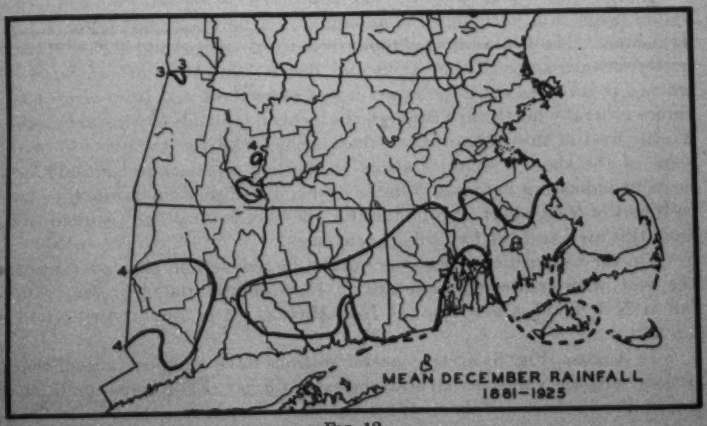
MEAN NOVEMBER RAINFALL
1881-1925

FIG. 11.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MEAN DECEMBER RAINFALL
1881-1925

FIG. 12.

Kingston, with 4.5 in., has the highest mean and Williamstown, with 2.6 in., has the lowest.

In May (Fig. 5) the mean rainfall is even less varied than in April and, for the region as a whole, is somewhat lower than in the previous month. In southeastern Massachusetts and Rhode Island there is a reaction towards a somewhat lower rainfall while in the region west of the Connecticut River there is an opposite reaction, most of the stations there having amounts of nearly 4 in. or over. The increasing contrast in the temperature between the coastal waters and the heated land favors lower rainfall, while the heating of the land induces increasing thunderstorm activity, thus producing a reverse effect in the interior.

The lowest mean is 2.9 in. at Nantucket and the highest, for the longer record stations, 4.3 in. at Cream Hill, Conn.

June (Fig. 6) has the lowest mean monthly rainfall for the region as a whole. The temperature contrast between the ocean and the land is larger than during the preceding month and there is, accordingly, a greater rainfall difference between these regions. West of the Connecticut River there are a few areas having more than 4 in. while to the eastward nearly all the mean values are in the neighborhood of 3 in., Cape Cod and the islands off the southern coast having the lowest mean values. Provincetown reports the lowest mean, 2.57 in.

In July (Fig. 7) the greater rainfall in the interior and the lower on the coasts, is most clearly shown. The southeastern portion still has mean values below 3 in. although the amounts, in general, are not quite so low as in June. The 4-in. isohyet extends from the neighborhood of New Haven northeastward across Connecticut and Rhode Island into Massachusetts, whence it recurves southwestward into Connecticut and from there continues generally northward through the Central Uplands of Massachusetts. To the west of this isohyet, the values are generally well above 4 in. with some of the shorter record stations in western Massachusetts and Connecticut indicating values of 5 in. or over. Because of unsatisfactory adjustment of these short record stations, the 5-in. isohyet has been omitted from this map and the two subsequent ones.

On the Connecticut coast the rainfall increases from the east towards the west, with greater continentality. For example, the mean July rainfall at New London is 3.4 in., at New Haven, 4.2 in. and at Bridgeport, 4.8 in.

In August (Fig. 8) all the coastal stations have a higher rainfall than in July and the values at all stations exceed 3 in. Elsewhere conditions are similar to those of July except in the southern portion, the 4-in. isohyet pushes eastward nearly to Narragansett Bay, while along the Massachusetts-Connecticut boundary there is a westward bend of this line to the Connecticut Valley. From New Haven eastward along the coast, the rainfall is under 4 in., these values being less than is indicated a short distance inland.

On the September mean rainfall map (Fig. 9) the 3-in. isohyet is again shown on the southeastern coast, while the 4-in. line has retreated to western Massachusetts and Connecticut. The lowest mean value is 2.55 in. at Nantucket, and the highest for the longer record stations, 4.4 in. at Falls Village, Conn.

October (Fig. 10) shows a decided marine type increase in the southern and southeastern portions while there is a marked continental type of decrease in the northern and western portions. Areas of 4 in. or over are confined to the southern and southwestern parts. In northern Massachusetts the average is about 3 in., a few stations having values slightly below that figure.

In November (Fig. 11) the rainfall in the northern portion is somewhat higher than in October, while there is little difference in the southern part. In western Connecticut however, there is a slight decrease. Southern and central Rhode Island are enclosed by the 4-in. isohyet, these being the only areas of any extent reporting values above 4 in. Williamstown is the only station to have a mean rainfall below 3 in.

In December (Fig. 12) the conditions are similar to those of January, February, and March, the higher rainfall being in the southern portion and the least in the northern. Kingston with 4.9 in., has the highest mean rainfall while Williamstown, as in the case of the mean November rainfall, is the only station having under 3 in.

Mean Monthly Rainfall of Southern New England.

Massachusetts.

Station.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Acushnet	4.30	4.22	4.52	3.87	3.88	3.03	3.23	3.79	3.39	4.07	4.06	4.37
Agawam	3.5	4.3	4.0	3.7	4.4	3.9	4.5	4.3	4.4	3.9	3.8	4.3
Amherst	3.58	3.44	3.81	3.13	3.49	4.18	4.18	4.10	4.02	3.33	3.36	3.57
Ashby	3.5	3.3	3.6	4.1	4.2	3.7	3.7	4.4	3.6	4.1	4.7	3.6
Ashland	4.09	4.18	4.23	3.55	3.24	3.05	3.43	3.39	3.54	3.32	3.54	3.88
Attleborough	4.3	4.1	4.2	3.8	3.5	3.1	3.7	3.6	3.8	3.2	3.8	3.6
Bedford	3.5	3.4	3.45	3.0	3.1	3.2	3.6	3.4	3.4	3.15	3.1	3.3
Belchertown	3.7	3.5	3.7	3.0	3.4	3.6	3.8	3.8	3.4	3.0	3.2	3.2
Blue Hill (Summit)	4.19	3.90	4.19	3.70	3.58	3.41	4.00	3.83	4.01	3.80	3.72	3.90
Blue Hill (Valley)	4.1	3.7	4.1	3.5	3.5	3.1	3.9	3.6	3.7	3.7	3.7	3.8
Boston	3.59	3.38	3.57	3.30	3.32	2.93	3.31	3.41	3.23	3.11	3.20	3.28
Boylston	4.0	4.0	4.3	3.9	3.5	3.7	4.0	4.0	3.8	3.4	3.8	3.9
Bridgewater	4.3	4.0	4.35	3.7	3.5	3.1	3.7	3.8	3.55	3.6	3.6	3.8
Brockton	3.67	3.37	3.75	3.16	3.34	3.06	3.37	3.38	3.49	3.33	3.41	3.40
Cambridge	3.91	3.73	3.86	3.55	3.27	3.08	3.35	3.34	3.46	3.17	3.48	3.48
Chester	3.8	4.0	3.6	3.4	3.3	3.2	4.7	4.1	3.8	3.3	3.9	3.5
Chestnut Hill	4.25	4.21	4.07	3.77	3.50	3.38	3.60	3.68	3.75	3.55	3.66	3.83
Clinton	3.76	3.72	3.95	3.17	3.23	3.33	3.72	3.76	3.48	3.33	3.57	3.74
Colrain	3.4	3.3	3.5	4.0	3.9	4.0	4.0	3.8	3.6	3.5	3.9	3.8
Concord	3.5	3.4	3.5	3.2	3.4	3.3	3.7	3.4	3.5	3.2	3.4	3.4
Cotuit	3.6	3.6	3.8	3.6	3.3	2.6	2.8	3.8	3.6	4.0	3.5	3.9
Dalton	3.5	3.4	3.8	3.1	3.4	3.4	4.7	4.0	4.1	3.0	3.3	3.2
Dudley	3.6	3.6	4.1	3.2	3.4	3.3	3.7	3.8	3.6	3.3	3.4	3.8
Easthampton	4.0	3.9	4.7	4.1	4.2	4.9	4.4	5.0	5.0	4.6	4.1	4.1
Egremont	3.2	3.3	3.2	3.4	3.6	3.8	4.5	4.3	4.1	3.2	3.2	3.5
Fall River	4.44	3.97	4.35	3.83	3.57	2.98	3.35	3.79	3.21	3.84	3.95	3.94
Fitchburg	3.57	3.28	3.49	3.14	3.42	3.40	3.86	3.81	3.66	3.27	3.49	3.49
Framingham	4.10	4.02	4.14	3.53	3.36	3.23	3.50	3.55	3.49	3.43	3.66	3.87
Gardner	3.9	3.7	3.9	4.1	3.5	3.5	3.9	4.3	3.5	3.5	3.9	3.8
Gloucester	4.3	4.3	4.9	3.7	3.8	3.6	3.6	3.5	3.4	3.9	4.0	4.1
Granville (a)	3.75	3.75	3.75	3.5	3.85	3.4	4.7	5.1	4.2	4.2	3.7	3.5
Granville (b)	4.3	4.7	4.9	4.2	3.9	3.6	4.7	4.5	4.6	3.9	4.8	4.5
Groton	3.5	3.5	3.7	3.5	3.4	3.4	3.3	3.7	3.7	3.4	3.5	3.4
Haverhill	3.5	3.5	3.8	3.3	3.3	3.3	3.5	3.0	3.3	3.4	3.2	3.4
Hingham	4.05	4.83	3.89	3.63	3.50	3.22	3.87	3.75	3.67	3.91	3.78	3.92
Holden	3.72	3.66	4.12	3.44	3.58	3.45	4.20	3.81	3.85	3.65	3.78	3.74
Holyoke	3.7	3.8	4.2	3.5	4.0	3.8	4.7	4.2	3.8	4.0	3.5	3.9
Hyannis	4.2	3.8	4.5	3.55	3.6	3.1	3.1	3.5	2.9	3.55	3.8	3.9
Ipswich	4.35	4.3	4.25	4.3	3.6	3.9	3.3	3.2	3.3	3.7	4.0	3.7
Lakeville	4.41	4.01	4.50	3.75	3.77	3.18	3.33	3.51	3.34	3.77	3.76	3.99
Lawrence	3.71	3.56	3.86	3.31	3.36	3.19	3.70	3.29	3.27	3.11	3.41	3.53
Leeds	3.97	4.08	4.23	3.57	4.20	3.70	4.18	4.53	4.00	3.68	3.62	3.89
Leicester	3.68	3.45	4.11	3.44	3.49	3.27	3.97	3.96	3.59	3.48	3.58	3.61
Leominster	3.53	3.47	3.68	3.30	3.66	3.46	4.01	3.95	3.77	3.41	3.57	3.56
Lincoln	2.9	3.1	3.2	3.1	3.6	3.2	3.9	3.2	3.4	3.4	3.1	2.9
Littleton	2.95	2.65	3.0	3.0	3.1	2.8	3.3	3.7	3.5	3.35	3.25	3.0
Lowell	3.89	4.03	4.03	3.64	3.50	3.35	3.62	3.61	3.56	3.21	3.62	3.72
Ludlow	3.25	3.07	3.58	3.09	3.37	3.38	4.36	3.88	3.60	3.36	3.21	3.38
Lynn	3.67	3.48	3.66	3.37	3.36	3.27	3.26	3.61	3.33	3.33	3.28	3.41
Manchester	3.8	3.8	3.7	3.7	3.6	3.0	3.3	3.4	3.6	3.5	3.7	3.5
Mansfield	4.8	4.05	3.9	4.15	3.6	3.7	4.15	3.9	4.3	3.85	3.85	4.35
Marlborough	3.5	3.5	3.5	3.2	3.5	3.2	3.7	3.4	3.5	3.5	3.7	3.3
Middleboro	4.4	4.1	4.2	3.6	3.3	3.1	3.4	3.4	3.3	3.8	3.5	3.8
Monroe Bridge	3.4	3.3	3.6	3.0	4.0	4.2	4.3	4.5	3.5	3.9	3.6	3.6
Monson	3.4	3.7	3.6	3.0	3.5	3.3	4.1	4.0	3.8	3.4	3.5	3.7
Nantucket	4.03	3.60	4.00	3.00	3.09	2.90	2.74	3.36	2.58	3.70	3.39	3.92
Natick	4.07	4.02	4.02	3.49	3.23	3.25	3.49	3.44	3.62	3.40	3.54	3.78
New Bedford	4.47	4.15	4.45	4.90	3.76	3.05	3.35	3.94	3.34	3.80	3.72	4.10

MEAN MONTHLY RAINFALL OF SOUTHERN NEW ENGLAND.
Massachusetts (Continued).

Station.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Newburyport	3.0	3.0	3.1	3.2	3.3	3.1	3.35	3.0	2.95	3.6	3.4	3.0
Newton	4.0	3.6	3.9	3.7	3.3	3.4	3.3	3.6	3.6	3.0	3.2	3.5
Norfolk	4.0	3.4	3.5	3.3	3.4	3.0	4.1	4.0	4.0	3.9	3.5	3.6
North Adams	3.6	3.0	3.6	3.1	3.3	3.9	4.3	4.5	3.7	3.5	3.3	3.6
North Billerica	3.4	3.4	3.6	3.4	3.3	3.5	3.8	3.5	3.2	3.3	3.6	3.3
Northbridge	4.07	3.80	4.18	3.48	3.52	3.33	3.81	3.98	3.59	3.65	3.68	3.76
Norwood	3.6	3.2	3.45	3.45	3.4	3.85	4.4	4.35	4.0	3.5	3.0	3.4
Otis	3.5	3.8	3.8	3.5	3.4	3.5	5.3	3.5	4.0	3.5	3.7	3.0
Peabody	3.9	3.8	3.6	3.3	3.9	3.5	3.5	4.0	3.3	3.7	4.0	3.6
Pembroke	4.1	3.7	4.5	3.8	3.5	3.2	3.6	3.6	3.0	3.5	3.9	4.0
Peru	3.6	3.8	4.1	3.4	3.5	3.8	4.8	4.5	4.5	2.9	3.6	3.4
Petersham	3.8	3.1	3.45	3.1	3.2	3.5	4.4	5.4	3.95	3.7	3.8	3.6
Pittsfield	3.3	3.4	3.6	2.9	3.2	3.5	4.3	4.1	4.0	3.05	3.05	3.4
Plymouth	4.55	4.26	4.44	4.16	3.48	3.12	3.25	3.51	3.14	3.98	3.99	4.09
Prescott	3.3	3.5	4.1	3.7	3.2	4.1	4.3	4.3	4.1	3.5	3.5	3.6
Princeton	3.98	3.49	3.90	3.58	3.47	3.53	4.34	4.35	3.61	3.46	3.75	3.64
Provincetown	3.92	3.35	3.66	3.45	3.21	2.57	2.69	3.06	2.91	3.48	3.06	3.58
Quincy	3.8	3.7	3.7	3.4	3.1	3.4	3.9	4.0	3.6	3.6	3.6	3.4
Reading	3.9	3.8	3.8	3.9	3.1	3.4	3.6	3.5	3.3	3.4	3.8	3.3
Rochester	4.6	4.3	4.5	4.2	3.9	3.6	3.7	3.8	3.4	4.15	4.1	4.05
Rockport	4.0	3.5	3.8	3.7	3.3	3.1	3.8	3.4	3.4	3.5	3.7	3.9
Rowe	3.4	3.1	3.0	3.0	3.7	3.8	3.9	4.2	4.3	3.9	3.3	3.5
Rutland	3.5	3.3	3.8	3.5	3.7	3.6	4.3	4.4	3.7	3.7	3.5	3.3
Salem	3.6	3.5	3.5	3.7	3.4	3.2	3.2	3.5	3.4	3.2	3.5	3.5
Savoy	3.9	3.9	3.1	2.8	4.3	4.9	5.0	4.6	3.8	3.8	3.5	3.7
Sharon	4.3	4.0	3.9	3.5	3.4	3.0	3.9	3.9	3.4	3.6	3.4	3.8
Shelburne Falls	2.6	2.9	2.7	2.8	4.1	3.5	3.8	4.0	3.3	3.8	3.4	3.3
Somerset	4.18	3.94	4.33	3.90	3.51	3.01	3.41	3.65	3.33	3.62	3.70	3.75
Somerville	3.6	3.5	3.7	3.6	3.5	3.2	3.6	3.4	3.7	3.4	3.5	3.6
Southampton	3.9	3.9	4.0	3.8	4.2	4.1	4.3	4.3	4.3	4.1	3.8	3.6
Southboro	4.34	4.30	4.32	3.85	3.39	3.45	3.59	3.62	3.74	3.51	3.92	4.06
Southbridge	3.6	3.8	3.85	3.6	4.0	2.85	3.9	3.7	3.8	3.6	3.7	3.5
Springfield	3.46	3.64	3.61	2.97	3.36	3.45	4.19	3.96	3.72	3.57	3.26	3.32
Sterling	3.5	3.7	3.7	3.3	3.4	3.5	3.8	3.8	3.4	3.5	3.6	3.8
Stoneham	3.9	4.0	3.9	3.8	3.4	3.7	3.5	3.6	3.5	3.4	3.3	3.6
Taunton	4.73	4.32	4.43	4.07	3.70	3.21	3.80	3.77	3.75	3.84	3.89	4.16
Templeton	3.3	3.3	3.6	2.9	3.05	2.95	3.7	3.85	3.4	2.85	3.45	3.45
Turners Falls	3.3	2.9	3.5	2.9	3.4	3.1	3.5	3.8	3.7	3.0	3.1	3.3
Vineyard Haven	3.9	3.7	4.1	3.5	3.4	2.9	2.6	3.4	2.6	4.1	3.9	4.2
Walpole	3.8	3.4	3.6	3.4	3.3	2.8	4.0	3.7	3.4	3.5	3.2	3.6
Waltham	3.65	3.49	3.61	3.53	3.43	3.33	3.70	3.62	3.76	3.44	3.54	3.48
Wareham	4.2	4.3	4.9	3.8	3.8	3.0	3.3	3.7	3.3	3.7	3.5	4.0
Warren	3.3	3.1	3.8	3.0	3.0	3.0	4.1	4.4	3.3	3.3	3.3	3.0
Webster	3.64	3.82	4.09	3.36	3.34	3.31	3.63	3.73	3.59	3.23	3.36	3.73
Wenham	3.46	3.28	3.48	3.30	3.56	3.62	3.80	3.50	3.67	3.46	3.62	3.40
Westborough	3.79	3.97	3.98	3.42	3.56	3.38	3.64	3.81	3.50	3.57	3.81	3.54
West Brookfield	3.1	3.1	3.5	3.1	3.1	3.2	4.3	4.3	3.6	3.4	3.2	3.1
Westfield	4.2	4.4	4.0	3.7	3.8	3.8	4.4	4.8	4.2	4.0	4.1	4.1
West Granville	3.9	4.2	3.9	4.2	3.8	3.2	5.1	5.2	4.1	4.1	2.8	3.0
Westminster	4.2	4.1	4.1	4.0	4.5	3.8	3.9	4.4	4.2	3.9	4.4	3.9
Weston	3.9	3.9	4.1	3.5	3.3	3.7	3.7	3.6	3.7	3.2	3.6	3.6
Williamsburg	3.1	3.1	3.5	3.1	4.0	3.4	4.1	3.9	4.1	3.9	3.7	3.7
Williamstown	2.73	2.52	3.00	2.63	3.12	3.43	4.12	4.12	3.50	2.93	2.77	2.96
Winchendon	3.4	3.2	3.5	3.2	3.3	3.4	4.0	4.3	4.0	3.2	3.5	3.4
Winchester	3.6	3.5	3.6	3.0	3.0	3.3	3.3	3.6	3.4	3.0	3.5	3.5
Woods Hole	3.7	3.85	4.0	3.6	3.1	2.6	3.2	3.1	2.8	3.85	3.4	3.8
Worcester	3.34	3.41	3.62	3.20	3.22	3.11	3.59	3.61	3.54	3.24	3.49	3.41
Worthington	3.5	4.2	3.7	3.2	4.4	3.8	4.7	4.0	4.6	3.1	3.7	3.9

MEAN MONTHLY RAINFALL OF SOUTHERN NEW ENGLAND.

Connecticut.

Station.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Bridgeport	4.02	3.72	4.35	3.54	3.89	3.20	4.83	4.48	3.76	4.11	3.43	4.05
Burlington (a)	3.4	3.5	3.5	3.8	3.9	3.4	5.0	4.7	4.1	4.0	3.7	3.4
Burlington (b)	4.5	4.3	4.45	4.25	4.1	3.7	4.5	4.6	4.1	4.4	4.5	3.7
Canton	3.93	3.79	3.80	3.59	3.92	3.70	4.46	4.23	4.23	4.06	3.64	3.94
Colchester	4.7	4.3	4.7	4.2	3.9	3.2	4.0	4.5	3.6	4.2	3.9	4.3
Cream Hill	4.1	3.6	3.5	4.0	4.3	4.35	3.95	4.2	3.5	3.95	3.55	3.6
Danielson	4.5	4.1	4.2	3.1	3.3	3.2	3.55	4.1	4.0	3.3	3.95	3.7
Enfield	3.3	3.4	3.3	3.4	3.9	4.2	4.3	3.7	4.6	3.5	3.5	3.6
Falls Village	3.30	3.48	3.40	3.05	3.79	3.59	4.55	4.14	4.44	3.31	3.25	3.49
Greenwich	3.70	3.57	3.71	3.29	3.63	3.26	4.14	4.34	3.50	3.71	3.21	3.57
Hartford	3.55	3.50	3.65	3.37	3.63	3.11	4.26	4.28	3.81	3.73	3.50	3.61
Hartland	4.6	4.5	4.3	2.7	3.8	4.0	4.9	5.1	4.1	4.2	4.4	4.0
Lake Konomoc	4.1	4.3	4.4	2.8	3.8	2.9	3.35	4.05	3.4	3.7	3.8	4.3
Mansfield	3.9	3.8	4.2	3.4	3.3	3.2	4.4	3.9	3.5	3.7	3.3	3.6
Middletown	4.08	4.01	4.33	3.52	3.81	3.19	4.05	4.14	3.64	4.05	3.71	4.10
Nepaug	4.4	3.8	4.1	3.6	3.9	3.2	4.6	4.6	4.5	4.1	3.6	3.7
New Haven	4.01	3.92	4.03	3.46	3.80	3.14	4.24	3.92	3.52	3.71	3.22	3.90
New London	4.12	3.88	3.90	3.54	3.54	3.11	3.45	3.86	3.39	3.64	3.41	3.74
Newtown	4.0	4.0	4.0	3.7	4.1	3.2	4.5	4.2	4.1	3.5	3.8	4.0
North Grosvenor Dale	4.1	4.0	4.2	3.5	3.5	3.2	3.9	3.8	3.5	3.4	3.5	3.8
Norwalk	3.73	3.82	4.17	3.28	3.87	3.10	4.59	4.68	3.82	3.97	3.29	3.80
Norwich	3.87	3.55	3.93	3.56	3.31	3.01	3.61	3.91	3.32	3.49	3.31	3.77
Simsbury	3.8	3.6	3.75	3.2	3.5	3.3	4.05	4.0	3.9	3.8	3.4	3.7
Southington	3.78	3.61	4.00	3.00	3.56	3.01	3.94	4.02	3.67	3.51	3.28	3.87
Voluntown	4.34	4.27	4.28	3.81	3.46	3.10	3.85	3.88	3.58	3.70	3.81	4.24
Wallingford	4.53	4.47	4.16	3.62	3.90	3.32	4.06	3.71	3.54	3.77	3.67	4.45
Waterbury	4.23	4.21	4.07	3.51	3.88	3.45	4.54	4.35	3.69	3.85	3.33	4.16

MEAN MONTHLY RAINFALL OF SOUTHERN NEW ENGLAND.

Rhode Island.

Station.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Block Island	3.83	3.68	3.90	3.61	3.49	2.64	3.04	3.45	2.68	3.52	3.59	3.78
Bristol	4.17	4.05	4.14	3.63	3.22	3.00	2.96	3.35	2.88	3.29	3.43	3.76
Foster	4.3	4.2	4.6	4.1	3.8	3.2	4.0	4.1	4.1	3.7	3.9	4.4
Hope	4.70	4.35	4.48	4.11	3.71	3.27	3.87	3.91	3.79	3.83	4.00	4.30
Hopkinton	5.0	4.3	5.1	4.1	3.4	3.7	4.1	4.3	3.6	4.3	4.4	4.5
Kingston	5.21	4.89	5.01	4.51	4.19	3.32	3.54	4.38	3.59	4.31	4.25	4.94
Lonsdale	4.2	4.1	4.0	3.7	3.8	3.3	3.9	3.8	3.6	3.6	3.7	4.0
Narragansett Pier	4.44	4.05	4.56	4.01	3.90	3.08	3.29	3.92	3.27	3.79	3.85	4.07
Pawtucket	4.49	4.42	4.19	3.67	3.66	3.17	3.92	3.86	3.59	3.48	3.42	4.17
Providence	4.78	4.47	4.32	3.86	3.73	3.20	3.75	3.67	3.72	3.61	3.67	4.18
Scituate	4.2	4.1	4.2	3.8	3.8	3.1	3.8	4.2	3.7	3.6	3.6	4.1
South Scituate	4.4	4.2	4.5	4.0	3.6	3.3	4.3	4.2	3.9	3.6	3.85	4.15
Wallum Pond	4.2	3.4	4.0	3.3	3.4	3.6	4.2	3.9	3.4	3.6	4.2	3.5
Woonsocket	4.47	4.10	4.33	3.81	3.76	3.21	4.22	3.91	3.70	3.66	3.86	4.02

THE WATER SUPPLY OF CARACAS, VENEZUELA.

WITH NOTES ON CONDITIONS AFFECTING WATER SUPPLIES OF THE COUNTRY.

BY THORNDIKE SAVILLE.*

[*Read September 15, 1927.*]

INTRODUCTION.

Since 1920 Venezuela has rapidly grown in importance as one of the chief oil-producing countries of the world. From 500 000 barrels in 1920 production has risen to about 40 000 000 in 1926, an output exceeded only by that of three other countries. Coincidentally with the prosperity induced by the large investments of foreign oil companies, there has been a constant increase in agricultural exports, particularly of coffee, cocoa and cattle. Total exports in 1926 amounted to approximately $55 000 000, exclusive of oil. Although the oil industry is at present concentrated in a relatively small section of the country in the vicinity of Lake Maracaibo, at the extreme northwest portion of the country, the commercial activity engendered by it has been felt throughout the populated regions. Unusual prosperity is being enjoyed and is encouraged by the progressive policies of President Gomez, who has held office since 1909 and has established a stable government with practically no outstanding national debt.

Venezuela has a total area of 394 000 sq. miles, being approximately the size of the 14 North American states bordering on the Atlantic ocean and including West Virginia. The population, however, is less than 3 000 000 and is concentrated chiefly in the coastal belt with a width of from 50 to 100 miles. All of the larger cities are within 50 miles of the coast.

Within recent years, a considerable movement of population to these cities has followed increased commercial activity. This fact, coupled with the establishment of foreign colonies in some of the centers and a desire to attract tourists, has led the Government to prepare a large program of public-works construction, devoted to extending and improving the highway system and to bettering sanitary conditions in the cities.

With a view towards improving the water supplies and sewerage systems of the larger cities, the Government of Venezuela in 1925 requested the International Health Board of the Rockefeller Foundation to send a sanitary engineer to the country to act in an advisory capacity, and to organize the Bureau of Sanitary Engineering in the National Health Service. The author was granted leave of absence from the University of North Carolina to undertake this work and, after a preliminary inspection trip in March, spent nine months in Venezuela, beginning in July, 1926.

This paper is confined chiefly to an exposition of investigations for the additional water supply of the city of Caracas. It presents conditions

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obtaining in several of the South American countries and makes available the results of meteorological and hydrological studies of which no ready compilations can be found in most South American countries. Engineering literature in the United States is quite devoid of such presentations, while British, French and German engineers have surpassed our own in making such information available. It is believed that the investigations herein reported will prove of value to American engineers because of increasing American interest in South America and because of the probability that within a few years American firms will be called upon to construct water supply and other public works in these countries on a large scale.

Geology and Topography of Venezuela.

The northern mountain ranges, offshoots of the Andes, that run along the northern part of the country comprise one of four geologic and topographic zones into which Venezuela may be divided. The center line of these ranges runs approximately from east to west through the principal cities of San Cristobal, Merida, Trujillo, Valencia, Maracay, and Caracas. A subsidiary range runs from Barcelona eastward over the Peninsula of Paria. These mountains are of archaic gneisses and schists, with granite intrusions forming the principal peaks. The elevations range from 3 000 to 15 000 ft. above sea level. They have exerted an important influence upon the development of the country by offering a barrier between the sea and the great, fertile, interior plains and plateaus. Many of the principal cities are located in valleys in these mountain ranges where the general elevation of about 3 000 ft. offers the best climatic conditions to be found in the country.

The second zone comprises the great plains, or "llanos," lying to the south of the mountain ranges and extending to the Orinoco River. They are sparsely populated, hot and humid and are subject, in large part, to periodical inundation and consequent high prevalence of malaria. Towns in this region are foci of malaria infection. Geologically this area is composed largely of consolidated sedimentary deposits which are now being prospected for oil.

The third zone comprises the dissected plateau known as the Guayana Highlands, covering all of the country south of the Orinoco. This region is densely wooded, contains most of the valuable mineral deposits of the country, is little explored and forms the home of uncivilized Indian tribes. The rocks are in general Archean gneisses and schists with granite intrusions.

The fourth zone is the area surrounding the Maracaibo basin, a hot and arid region of coastal plain sediments and the site of the great oil deposits now being worked.

Present Water Supply of Caracas.

To reach Caracas, the capital city of Venezuela, one enters the country at the principal port of La Guaira, located at the foot of the coastal range

of mountains. One proceeds up the side of the mountains, either by railroad or on a splendid new concrete highway which requires 28 miles of length to accomplish the 8 miles by airline between La Guaira and Caracas. (Fig. 1.) The city of Caracas lies just over the crest of the coastal range and is situated in the small valley of the Guaire River, being almost entirely surrounded by mountains. The densely settled old city was built along the north bank of the river on the mountain slopes at elevations of 2 800 to 3 500 ft. The newer residential area lies to the south of the river. The Guaire River, just above the city, has a drainage area of approximately 121 sq. miles and, just below the city, of 131 sq. miles. The intervening 10 sq. miles are drained largely by the Caroata, Catuche, and Anauco creeks which flow through the city. The city is growing rapidly in all directions except to the north, where the precipitous mountain slopes obstruct street construction and delivery of water from present sources. The city is sewered chiefly on the combined system, large collectors running along the principal creeks and discharging into a main interceptor along the bank of the river. The sewerage system is still under construction. About $1 500 000 have, so far, been spent on it.*

At present, the water supply of Caracas has two general sources. The low-level supply, constituting approximately 86 per cent. of the total supply, comes from the Macarao River, a head-water tributary of the River Guaire, with a drainage area of about 34.4 sq. miles. The high-level supply for the extreme northern part of the city comes from the head waters of Catuche and Cotiza creeks, with a combined drainage area of about 3.8 sq. miles.

Macarao Supply. The catchment area above the intake of this supply is mountainous in character and is drained by several small streams. Some of these streams have considerable agricultural populations on their upper collecting grounds, and there are a number of "haciendas" in the Macarao Valley, itself devoted chiefly to the raising of sugar cane. The total population of the watershed is estimated at about 1 500 persons. The entire area is practically barren, apart from the grass on the mountain sides and the crops raised in the valleys. The slopes are precipitous and the surface of decomposed rock (mostly gneiss and schist, with some granite) erodes rapidly. Practically all of the rainfall occurs in heavy showers lasting about an hour, and the resulting flood run-off is sudden and heavy, carrying large amounts of débris into the river and into the intake canal, making it necessary to clear the canal after nearly every flood. In spite of the torrential character of the rains there is an appreciable amount of ground storage in the gravel deposits of the Macarao Valley, but this is rapidly depleted, during the dry season, by seepage into the stream and by evaporation from the cane plantations. (See Fig. 10, p. 334.)

The method of taking water from the river is shown in Fig. 2. The river leads directly into a rectangular brick canal, about 600 ft. long and having a maximum capacity of only 8 m.g.d. The canal discharges into

*A description of the sewerage system will appear shortly in *Engineering News-Record*.

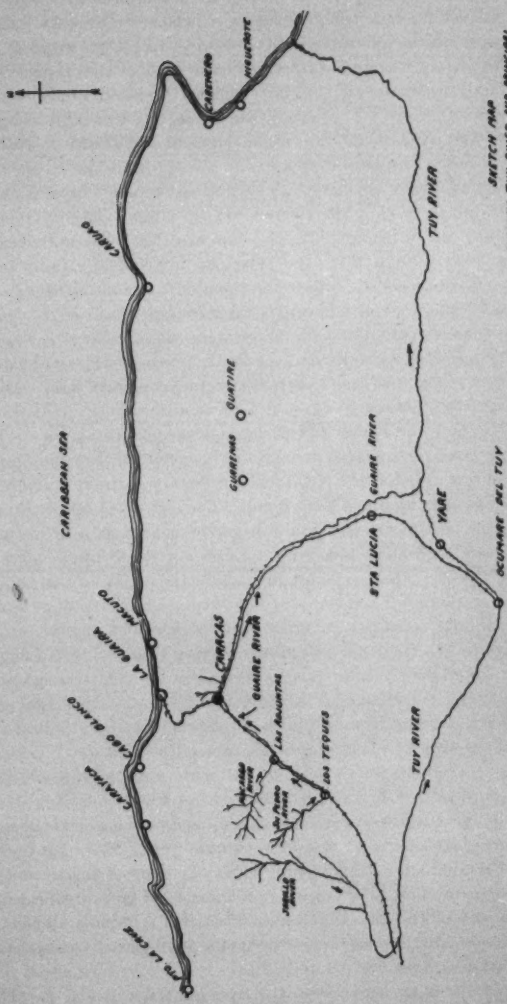
SKETCH MAP
SHOWING TUY RIVER AND PRINCIPAL
TRIBUTARIES NEAR CARACAS
CARIBBEAN SEA
CARUAO
CARENERO
HIGUEROTE
GUARENAS
GUATIRE
GUAIRE RIVER
STA LUCIA
YARE
OCUMARE DEL TUY
TUY RIVER
CARACAS
LA GUAIRA
MACUTO
CABO BLANCO
CARAYACA
LAS ADJUNTAS
LOS TEQUES
TUY RIVER

FIG. 1.

both a cast-iron pipe line and a concrete aqueduct which convey the water to Caracas and some intermediate points. There are two sand traps or settling basins in the canal, but velocities through them are so great that they are ineffective in removing suspended matter other than large gravel.

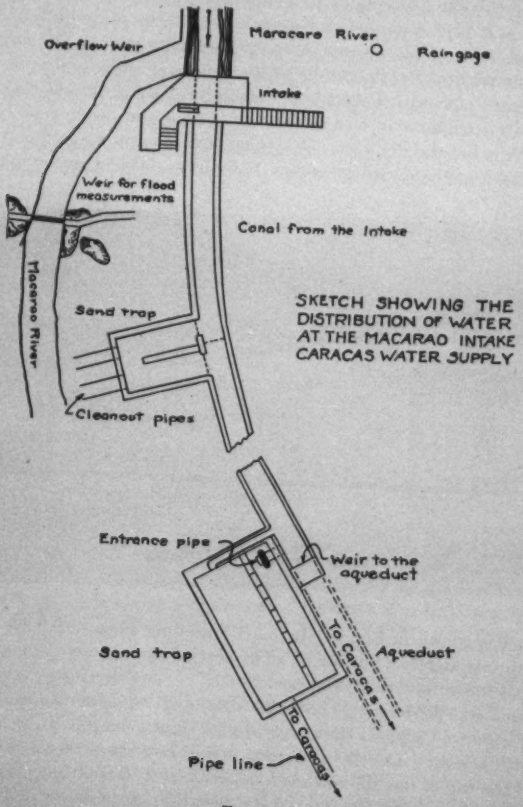

FIG. 2.

Much gravel and sand is deposited in the canal, and considerable quantities of sand are carried into the aqueduct.

The pipe line is of cast iron 18 in. in diameter with lead joints and follows in general the roads to Caracas. From it are supplied the towns of Macarao, Las Adjuntas, Antimano, and Carapa. Water is delivered to it under an essentially constant head, and measurements indicate that it

carries about 3.3 m.g.d. It discharges eventually into the Calvario Reservoir at Caracas.

The aqueduct, prior to 1917, was simply an open canal in earth cut which followed a grade contour to Caracas. Losses from evaporation and leakage in this canal amounted to 50–100 per cent. of the total flow. During 1916 and 1917 a reinforced concrete canal, trapezoidal in shape, with reinforced concrete slab cover was constructed in its place. The length was reduced by crossing five deep gullies with siphons of asphalt-covered, spiral, riveted, steel pipe with bolted joints made by Abendroth and Root, New York. These siphons totaled 6 100 ft. in length and resulted in a saving of 41 000 ft. in total distance. A typical siphon is shown in Fig. 3. The entire length of the aqueduct is now 20.6 miles. The cross-section of the

FIG. 3. — TYPICAL SIPHON IN MACARAO AQUEDUCT.

aqueduct is shown in Fig. 4. It has a minimum slope of 0.0008 and will carry approximately 11.4 m.g.d. The cost of the concrete aqueduct was $2.10 per lineal foot, or $16.15 per cu. yd.

Low-Level Reservoirs. The pipe line and aqueduct from Macarao deliver water to Calvario Reservoir, located on a small hill in the northeast part of Caracas. This is a covered, reinforced concrete reservoir built around the top of the hill and has a capacity of 2 500 000 gal. The elevation of the bottom is 3 180 ft., and the elevation of the water surface when full is 3 200 ft. A branch pipe from the aqueduct discharges into Guarataro Reservoir, located near Calvario Reservoir, but at a lower elevation. This uncovered reservoir has a capacity of 790 000 gal. The bottom is at elevation 3 037 ft., and the water surface when full is at elevation 3 050 ft. The average consumption from the Macarao source is about 5.3 m.g.d., and total storage in the two reservoirs is 3 290 000 gal. or less than two-thirds of a day's supply.

Catuche and Cotiza Sources. To supply that portion of the city between elevations 3 150 and 3 500 ft., two mountain streams with a combined drainage area of about 3.8 sq. miles in the central northern part of the city have been diverted. The Catuche source has been in use since very early times, as the oldest part of Caracas lies adjacent to it. The Cotiza source was developed in 1917 and flows through a 7-in. cast-iron pipe 8 700 ft. long. It crosses numerous gullies on suspension cables and cost about $30 000. It delivers, at present, only about 342 000 gal. daily, but has sufficient capacity to deliver 770 000. The higher capacity was chosen so that the pipe could be extended in the future to tap additional sources on the Anauco and Gamboa creeks to the east. The combined average yield of the Catuche and Cotiza sources is about 800 000 gal. daily.

FIG. 4. — SECTION OF NEW CONCRETE AQUEDUCT DURING CONSTRUCTION. OLD OPEN CANAL IN FOREGROUND.

High-Level Reservoirs. The two high-level sources discharge into the so-called Polvorin tanks, two small tanks with a total capacity of about 600 000 gal., and a maximum elevation of water surface of 3 447 ft.

Necessity for Additional Water Supply. During the extreme drought in the spring of 1926, the yield of the Macarao River during the minimum week in March was only 3.7 m.g.d., and that of the Catuche and Cotiza sources only 0.3 m.g.d. There were delivered to the city only about 3.4 m.g.d., equivalent to approximately 25 gal. per cap. daily. This scarcity caused much hardship. While the drought was of exceptional severity, the dry-weather supply frequently is as low as 4.5 m.g.d. or about 34 gal. per cap. daily, with the present inadequate and obsolete distribution system. Additional water supply for this rapidly growing city is imperative. A description of the author's investigations of new supplies follows:

Investigations of Additional Water Supply.

Population Growth. Population data for Caracas are available as far back as 1580. Neglecting the earlier figures, the average annual rate of increase from 1830 to 1920 was about 1.2 per cent. Between 1920 and 1924 it increased to 8.2 per cent. and then dropped to 3.5 per cent. from 1924 to 1926. It appears probable that a relatively high rate of increase will continue for a few years, being followed by lower rates as industrial conditions become more stable.

At present the Macarao source supplies water also to the town of Antimano and it is probable that it will be desirable for Caracas to furnish pure water also to El Valle, Sabana Grande, Chacao and possibly Los Chorros by 1935. The growth of these towns during past years is not known accurately. Their present population is approximately 8 000, and the average annual increase in population is unlikely to exceed 1 per cent.

The following estimates of future growth seem reasonable:

Year.	Average Annual Per Cent. of Increase.		Population.	
	Caracas.	Vicinity.	Caracas.	Caracas and Vicinity.
1926	...	...	135 250	137 750
1930	3.0	1.0	152 230	160 000
1940	2.0	1.0	185 500	192 000
1950	1.5	1.0	215 300	215 000

Water Consumption. The maximum quantity of water supplied at present to Caracas from its three sources is about 9.4 m.g.d., or 68 gal. per cap. daily. This, however, does not represent normal requirements because there is considerable leakage in supply and distribution mains, and when this amount is delivered to the city, water overflows during the night from the storage tanks and runs to waste.

In January, 1927, measurements of water quantity were made yielding the following values:

Source.	Supplied (gal. daily).
Macarao	5 043 000
Catuche	456 000
Cotiza	342 000
Total	5 841 000
Supplied to outlying districts and waste	685 000
Net quantity used in Caracas	5 156 000

This quantity caused no appreciable shortage of water in the city and may be regarded as the normal consumption with the present system of

distribution. It amounts to 38 gal. per cap. daily to the population of 135 250 of Caracas itself.

Actual measurements were made of the amount of water supplied to 62 houses, situated in 31 squares and receiving their supply under all conditions of distribution. The amount of water used by individual services varied greatly, the average being 60 gal. per cap. daily. This indicates what the demand may be when nearly all buildings in the city will be supplied with water.

Assuming an average future consumption of 53 gal. per cap. daily for the population of Caracas and vicinity, the quantities of water required will be as follows:

Year.	Population Supplied.	Daily Consumption. m.g.d.
1926	137 750	7.27
1930	160 000	8.43
1940	192 000	10.12
1950	215 000	11.35

Undoubtedly, it will be cheaper to supply Caracas and the surrounding towns with water from a system designed and operated as a whole, than to maintain and enlarge the present series of independent small supplies. To do the latter would be a temporary expedient at best, and in the long run more costly and less satisfactory than a well-conceived metropolitan water supply.

Annual and Seasonal Rainfall. Since no regular measurements of discharge had been made of the various streams that could be considered as sources of water supply for Caracas and since even on the principal present source, the Macarao, measurements are made only of the flow at the intake and these are not of high accuracy, it was necessary to investigate thoroughly the amount and distribution of rainfall in Caracas and the surrounding region.

Table 1 shows the annual rainfall at the various gaging stations in Caracas and vicinity. No rainfall stations were located on the Macarao watershed previous to October, 1926. Table 2 shows the monthly rainfall at Caracas Observatory. (See Fig. 10, p. 334.)

On account of the seasonal distribution of rainfall in the vicinity of Caracas, it seemed desirable to arrange the monthly rainfall in accordance with the climatic year, which was taken to begin in March. The rain which falls in January and February is of little value in supplying ground water, and does not ordinarily affect the run-off appreciably.

Figure 5 shows the distribution of rainfall in the (theoretical) normal year, and in extreme years, arranged on a climatic year basis.

Study of these and other tables shows that within a radius of 15.5 miles of Caracas there is a very marked variation in both monthly and annual rainfall. The local nature of the rainfall is further indicated by Table 3, showing the daily rainfall for October, 1926.

TABLE 1. — ANNUAL RAINFALL IN INCHES AT CARACAS AND VICINITY.

Year.	Los Teques.	Antimano.	Caracas. (1)	Caracas. (2)	Caracas. (3)	Caracas. (4)
1891	....	....	....	....	....	29.7
1892	....	....	....	....	....	47.4
1893	....	....	....	....	....	38.4
1894	....	....	....	....	....	24.3
1895	....	....	....	....	....	30.9
1896	....	....	....	....	....	29.4
1897	....	....	....	....	....	30.8
1898	....	....	....	....	....	30.1
1899	....	....	....	....	....	24.1
1900	....	....	....	....	....	34.0
1901	....	....	....	....	....	32.4
1902	....	....	....	....	....	30.8
1903	....	51.8	....	....	....	32.8
1904	....	48.2	....	....	....	32.4
1905	....	48.3	....	....	....	37.9
1906	....	63.9	....	....	....	35.9
1907	35.3	42.8	....	....	....	34.8
1908	45.7	44.5	....	32.4	....	31.0
1909	44.8	54.2	....	39.4	....	37.8
1910	37.1	45.8	....	29.6	....	31.2
1911	37.6	45.4	....	33.6	....	34.6
1912	46.2	50.8	....	30.4	....	25.1
1913	42.7	56.1	....	31.3	....	26.2
1914	38.6	48.9	22.6	22.6	....	19.7
1915	48.6	62.1	34.0	34.1	....	32.6
1916	48.1	63.0	35.0	35.0	....	36.1
1917	49.5	47.0	32.4	32.2	....	32.7
1918	53.9	45.2	29.7	29.8	....	29.9
1919	50.4	44.8	29.5	29.2	....	31.1
1920	25.0	42.4	25.6	25.6	....	30.3
1921	41.0	....	39.0	38.6	35.9	44.9
1922	34.4	....	28.4	26.5	28.5	29.3
1923	33.1	....	24.1	24.1	20.9	27.4
1924	52.2	....	40.6	37.8	32.5	41.8
1925	27.3	....	20.2	21.9	21.4	27.1
1926	44.9	....	35.1	....	35.6	40.9
Averages:						
1891 to 1926	....	....	....	....	....	32.4
1908 to 1925	....	....	....	30.8	....	31.6
1914 to 1926	....	....	30.5	....	....	32.6
1921 to 1926	....	....	....	....	29.1	35.2
1903 to 1920	....	50.3	....	....	....	31.8
1907 to 1926	41.8	....	....	....	....	32.2

Caracas (1) is at station of Gran Ferrocaril de Venezuela.
Caracas (2) is at station of English Railroad.
Caracas (3) is at office of Electric Power Co.
Caracas (4) is at Government Observatory.

It is evident from inspection of this table that there is no relation between daily rainfall at any of the stations.

Causes of Rainfall. The causes for the extraordinarily local aspect of rainfall in this region are to be found in two facts: (1) the annual movement and position of the "heat equator" and (2) the local topography. The heat equator is the belt of high temperature encircling the world near the geometric equator. It is the region of doldrums or ascending air currents

TABLE 2. — RAINFALL AT CARACAS OBSERVATORY. CLIMATIC YEAR.

Year.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Totals
1891–92	0.63	1.91	2.14	1.78	6.50	2.73	3.81	4.42	3.24	1.69	1.31	1.30	31.46
1892–93	1.45	3.77	7.30	6.29	7.65	4.83	3.77	5.44	3.49	0.75	0.16	0.34	45.24
1893–94	0.03	1.15	5.38	2.80	8.40	1.69	5.75	5.97	3.12	3.64	0.93	0.57	39.43
1894–95	0.20	0.71	1.62	1.20	2.38	5.02	3.91	2.55	3.10	2.10	2.39	0.14	25.32
1895–96	0.54	0.70	1.77	5.38	2.20	2.58	3.70	4.62	5.27	1.58	0.52	0.01	28.87
1896–97	0.19	4.54	4.33	4.66	1.44	2.74	1.31	2.54	5.04	2.14	1.60	0.15	30.68
1897–98	0.00	0.21	3.11	3.97	4.97	3.64	1.52	5.48	3.16	3.06	0.63	0.00	29.75
1898–99	2.69	0.70	0.94	3.11	4,23	5.94	4.07	3.12	4.15	0.48	0.61	0.17	30.21
1899–00	0.08	0.00	0.00	4.56	2.50	3.48	3.99	4.48	2.32	1.88	0.87	0.19	24.35
1900–01	1.95	0.78	0.57	3.48	7.30	5.53	3.47	5.56	4.31	0.00	0.65	0.02	33.62
1901–02	0.04	0.04	1.52	3.02	7.36	4.66	2.96	5.57	5.09	1.50	2.43	0.00	34.19
1902–03	0.00	0.60	3.32	4.91	3.73	2.97	7.01	2.05	1.06	2.69	0.17	0.00	28.51
1903–04	0.00	1.12	2.01	4.28	5.15	6.10	2.60	4.80	3.24	3.31	0.63	0.13	33.37
1904–05	3.99	6.45	1.57	3.76	2.88	4.86	3.26	2.95	1.42	0.48	0.38	0.10	32.10
1905–06	0.39	4.13	6.37	2.43	4.59	4.64	4.27	2.33	6.29	1.96	0.06	0.24	37.70
1906–07	0.00	0.16	3.75	7.08	4.97	4.07	4.36	5.26	2.20	3.70	3.91	0.29	39.75
1907–08	2.72	0.34	4.24	3.39	7.15	3.20	1.88	4.15	3.18	0.38	0.00	0.04	30.67
1908–09	0.02	1.96	2.45	3.58	2.64	4.48	7.48	4.47	2.30	1.62	1.68	0.18	32.86
1909–10	0.07	4.90	1.92	3.31	3.82	6.20	1.36	5.01	3.82	5.60	1.54	2.34	39.89
1910–11	0.98	1.42	5.97	5.26	1.18	3.75	2.26	1.99	3.41	1.15	0.06	1.00	28.43
1911–12	0.25	1.57	3.66	6.01	6.05	6.88	1.75	2.42	3.37	1.54	0.07	0.00	33.57
1912–13	0.00	0.13	1.06	4.42	5.50	4.31	3.41	1.77	3.19	1.23	1.77	0.03	26.82
1913–14	0.54	0.00	2.11	3.08	2.49	3.55	4.47	2.89	3.46	1.75	0.00	0.00	24.34
1914–15	0.04	0.23	3.18	5.15	1.36	2.36	1.71	2.86	1.86	0.97	0.77	1.93	22.42
1915–16	0.00	4.86	2.08	5.10	3.03	4.66	4.35	4.74	0.93	0.22	0.46	1.33	31.76
1916–17	0.55	0.13	1.74	3.17	4.99	6.65	7.39	2.30	5.74	1.65	0.61	0.58	35.50
1917–18	0.25	2.06	1.35	7.59	6.11	3.06	3.55	2.39	1.15	4.01	0.54	0.56	32.62
1918–19	0.50	1.17	3.99	4.90	5.50	4.93	1.31	4.20	1.85	0.42	0.05	0.01	28.83
1919–20	0.91	4.45	1.26	4.83	2.51	4.04	4.26	3.77	4.85	0.19	0.09	0.05	31.21
1920–21	0.24	0.00	3.64	5.57	3.88	3.14	8.25	1.73	3.09	0.64	0.99	0.01	31.18
1921–22	1.32	0.63	2.33	9.08	3.74	5.81	5.97	5.58	5.77	3.58	1.31	0.16	45.28
1922–23	0.28	0.04	5.10	2.76	1.61	3.08	4.30	5.35	3.40	1.87	2.67	0.00	30.46
1923–24	0.24	0.37	2.48	1.78	3.62	3.10	2.98	5.46	2.28	2.41	0.13	0.06	24.91
1924–25	0.08	1.78	2.37	2.92	6.00	6.07	9.40	6.75	5.98	0.31	0.23	0.07	41.96
1925–26	0.39	0.25	2.14	3.98	1.94	6.80	5.14	4.08	1.69	0.43	0.04	0.00	26.88
Totals	21.56	53.26	98.77	148.59	149.37	151.55	140.98	139.05	117.82	60.93	30.26	12.00	1 124.14
Average	0.62	1.52	2.82	4.24	4.27	4.33	4.06	3.97	3.37	1.72	0.86	0.34	32.12

TABLE 3. — DAILY RAINFALL IN VICINITY OF CARACAS.

	OCTOBER 1926.					
Day of Month.	Caracas Cajigal.	Caracas G.F.V.	Electricidad.	Tomodel Macarao.	El Guamo.	Los Teques.
1	0	0	0	0.16	....	0
2	0	0.08	0	0	....	0.32
3	0	0	0	0	....	0
4	0.10	0	0.20	0	....	0
5	0.64	0.82	0.47	0.29	....	0.41
6	0.11	0	0.05	0	....	0.45
7	0	0.08	0	0.16	....	0
8	0	0	0	0	....	0
9	0	0	0	0	....	0
10	0.89	0	0.41	0	....	0.70
11	0.95	0.50	1.00	0.10	0.18	0
12	0	0.83	0	0.58	0.28	0.10
13	0.05	0	0	0.04	0.18	0.45
14	1.77	0	0	0	0	0
15	0	T	0.63	0	0	0
16	0	1.56	0	0	0	0
17	0	0	0	0.04	0.47	0
18	0	0	0	0	0.28	0
19	0.12	0	0.04	0	0	0
20	0	0.10	0	0	0	0.32
21	0	0	0	0	0	0
22	1.29	0	1.61	0	0	0
23	0	0.96	0	0.30	0	0
24	0.06	0	T	0.29	0	0
25	0	0.05	0	0	0.55	0
26	0.94	0	0.20	0	0	0.40
27	0.17	0.36	0.07	0.66	0.43	0.43
28	0	0.07	0	0.49	0	0
29	0	0	0	0.55	0.20	0
30	2.22	0	0.61	0	0.31	0
31	0	1.73	0	0	0.79	0
Totals	9.31	7.14	5.29	3.66	3.67	3.58

and is distinguished by light winds and almost daily rains. The heat equator moves north and south of the geometric equator following the sun. The heat equator is farthest north in July or August, the months of maximum precipitation in Caracas. At this time its center lies on a curved line passing through Maracaibo, Guanare and a point about 90 miles south of Carabobo. The belt of the heat equator averages some 340 miles in width. Caracas is on its northern fringe, as is also the mouth of the Tuy River to which the Guaire River draining Caracas is tributary. (Fig. 1.)

To the north of the heat equator is the zone of the "northeast trades." These, flowing toward a hotter region than their origin, have a tendency to take up moisture, until they are sufficiently chilled by being forced up by land masses to cause precipitation.

In January or February, the heat equator is farthest south, and no part of it passes through Venezuela. In consequence, the period from November to March, when the heat equator is generally well south of Caracas, is largely governed by the northeast trade winds. These winds enter

the valley of the Tuy, turn into southeast winds on account of the direction of the river, and pass up to Caracas by the Guaire valley. What excess moisture they contain is usually mostly precipitated before they reach

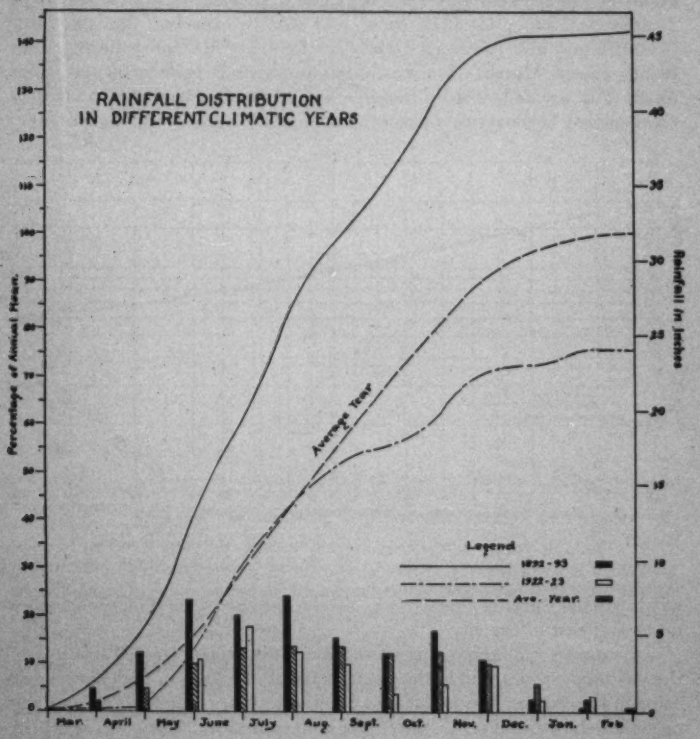

FIG. 5.

Caracas. Thus the dry-season rainfall at Ocumare del Tuy is ordinarily much greater than that at Caracas.

The sun passes the equator on its annual northward movement on March 21. As a result, the season of greatest heat in Venezuela is in April and May. The heat equator is also moving northward and the influence of the northeast trade winds is decreasing. The heat equator, or belt of vertical ascending wet winds, is closest to Caracas in June, July and August, and in consequence these are the hottest and rainiest months, as seen by Fig. 5. The northeast trades, weaker and more easterly than during the

winter, and therefore wetter and hotter, flow up the Tuy River, and as they are chilled, after heating at the bottom, by ascent up the Guaire valley, they precipitate their excess moisture all along their path. The excellent diagrams of wind direction by Dr. Luis Ugueto, published in the *Memorias de Instruccion Publica* for 1919, show, as would be expected, that the winds from the east and southeast greatly predominate in Caracas during every month except March. The northeast trade winds passing up the valley of the Tuy are deflected by the direction of the Guaire valley, so that at Caracas they become east and southeast winds. Little of the trade or other

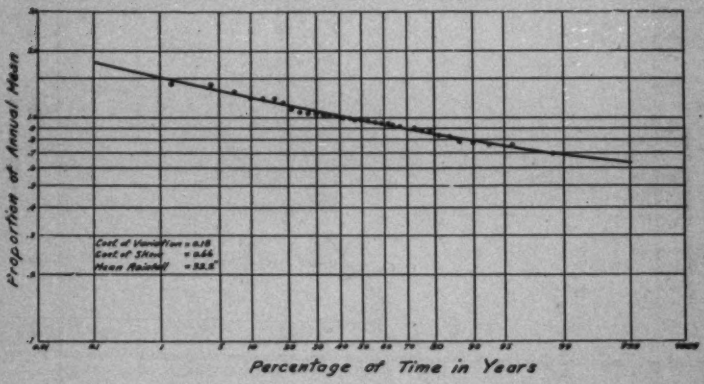

FIG. 6. — FREQUENCY OF OCCURRENCE OF CLIMATIC-YEAR RAINFALL.

winds reaches Caracas directly from the sea because of the mountain barrier north and east of the city.

Frequency of Low and High Rainfalls. It is evident from Table 2 that there is no definite trend in the annual rainfall. Cycles of high and of low rainfall alternate. The frequency of climatic years of very high and low rainfall is shown on Fig. 6. The minimum rainfall of 22.4 in. in 1914–1915 and the maximum of 45.3 in. in 1921–1922 may be expected to be equalled or exceeded about once in 71 years and once in 40 years respectively.

The year 1926 has provided striking evidence that severe droughts do not necessarily occur in years of minimum annual rainfall. The most severe drought ever experienced in Caracas occurred in March and April, 1926, but the annual rainfall for the year was 8.4 in. above the average. For this reason seasonal rainfall was investigated at certain of the stations. Table 4 shows the rainfall for the months of November to March inclusive at Caracas (Cajigal) and Los Teques. In general it is the amount of rainfall in these months which determines the severity of the dry season. It is seen by this method of analysis that the drought of 1926 was the most severe

in the 36 years of record at Caracas, whereas, in the 20 years of record at Los Teques, the most severe drought occurred in 1908. There is only moderate correlation between the severity of the dry seasons at the two places, the coefficient of correlation being 0.81.

TABLE 4. — DRY SEASON (NOVEMBER TO MARCH INCLUSIVE) RAINFALL IN INCHES AT CARACAS AND LOS TEQUES.

Year.	Caracas.	Los Teques.	Year.	Caracas.	Los Teques.
1891–92	11.11	.....	1911–12	4.99	6.12
1892–93	4.77	.....	1912–13	6.76	11.11
1893–94	8.51	.....	1913–14	5.26	9.45
1894–95	7.28	.....	1914–15	5.50	8.48
1895–96	7.58	.....	1915–16	3.48	6.03
1896–97	8.94	.....	1916–17	8.84	10.41
1897–98	9.72	.....	1917–18	6.78	8.36
1898–99	5.50	.....	1918–19	3.24	9.68
1899–1900	7.21	.....	1919–20	5.42	7.88
1900–01	5.02	.....	1920–21	6.06	7.45
1901–02	9.01	.....	1921–22	11.11	10.57
1902–03	3.92	.....	1922–23	8.17	9.08
1903–04	11.30	.....	1923–24	4.97	5.27
1904–05	2.79	.....	1924–25	6.98	11.00
1905–06	8.56	.....	1925–26	2.15	3.28
1906–07	13.22	8.26	1926–27	.....	.....
1907–08	3.62	2.29			
1908–09	5.85	10.14	Total	244.19	164.12
1909–10	14.69	11.30	Average	6.98	8.21
1910–11	5.88	7.96			

Figure 7 presents the variation in dry-season rainfall at Caracas. It is seen that the drought of 1926 (Table 4) is of a severity likely to be equaled or exceeded about once in 65 years. Reasonable provision for water supply should, therefore, be concerned with conditions somewhat worse than those experienced during that year, unless there is a progressive downward trend in rainfall.

In the extreme dry seasons, there is very little more rainfall at Los Teques, elevation 4 000 ft., than at Caracas, elevation 3 200 ft. This is shown in Table 4 for the dry years, 1908, 1912, 1916 and 1926. The year 1919 is a marked exception. The average dry-season rainfall at Los Teques is only 1.23 in. greater than that at Caracas. Los Teques, although higher in elevation, is farther up the valley and hence more distant from the primary source of water vapor than Caracas.

Secular Changes in Rainfall. In various previous investigations of rainfall at Caracas, conflicting statements have been made as to a progressive decrease in rainfall, some workers asserting that the rainfall was decreasing due to deforestation.

To investigate this subject the method of progressive means was used. A "smoothing" formula was employed of the type: $B=\frac{a+2b+c}{4}$, where a, b, and c equal rainfalls for three successive years, and B is the progressive

mean rainfall for the year with rainfall b. Values of B for each year of record are plotted in Fig. 8 for both annual and dry-season rainfalls. They indicate the cycles in rainfall in Caracas together with the computed trend. It is evident that neither the method of progressive means nor the trend line indicates any pronounced change in climate, but that the cycles of high and low rainfall are distributed more or less systematically about the mean. The slight downward trend in rainfalls is not sufficiently pronounced to be significant.

Sources of Additional Water Supply. The quantity of water delivered to the aqueduct each day for the period October, 1918, to December, 1926,

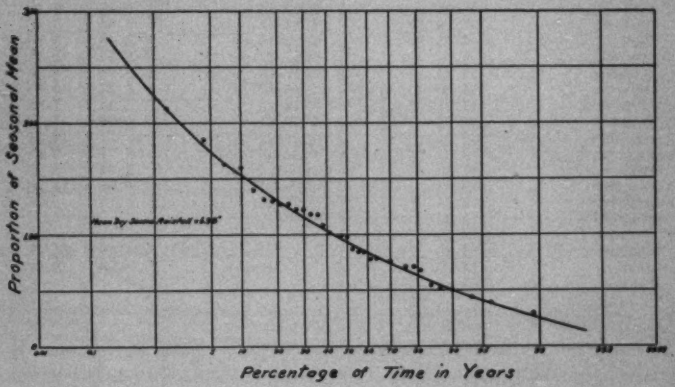

FIG. 7. — FREQUENCY OF OCCURRENCE OF DRY-SEASON RAINFALL.

has been more or less accurately measured by a weir. To this may be added an essentially constant quantity of 3.31 m.g.d., the capacity of the pipe line, to obtain the total quantity taken from the Macarao River. Table 5 shows the estimated total weekly flow of the Macarao River at the intake. This has been obtained by adding to the estimated flood flows the amount taken to the city. The method of obtaining the flood discharge will be indicated later.

Assuming the weekly variations in flow of the Macarao River and of the Catuche and Cotiza sources to be more or less the same, Table 6 has been prepared by subtracting a constant quantity of 0.57 m.g.d. from the water requirements as the flow from Catuche and Cotiza, and by finding from Table 5 the number of weeks in each year that the flow of the Macarao River was insufficient to supply the demand. This table, while not strictly accurate, is probably not in error by more than one or two weeks in any year.

It is evident from Tables 6 and 9, that the present sources of supply, as developed, are not adequate for Caracas during normal dry seasons, and

TABLE 5. — WEEKLY FLOW OF MACARAO RIVER IN 1 000 CUBIC METERS.*

Week.	1918.	1919.	1920.	1921.	1922.	1923.	1924.	1925.	1926.
1	...	162	184	183	216	207	206	208	125
2	...	150	186	199	174	193	190	199	117
3	...	156	184	204	178	192	178	202	112
4	...	156	184	180	183	190	161	193	114
5	...	155	184	183	189	198	150	181	115
6	...	152	184	178	190	183	137	179	111
7	...	155	184	185	214	171	131	180	111
8	...	149	183	172	200	173	152	182	108
9	...	147	184	170	201	163	141	171	107
10	...	149	224	225	208	143	132	181	106
11	...	155	183	174	192	215	119	177	105
12	...	156	184	176	255	218	113	182	105
13	...	161	184	235	305	282	107	172	100
14	...	157	184	317	272	151	109	149	98
15	...	157	184	185	202	166	113	156	104
16	...	280	156	249	184	152	123	148	105
17	...	397	168	214	184	187	134	145	104
18	...	197	170	197	182	188	143	148	117
19	...	213	170	304	179	210	123	129	125
20	...	178	154	184	253	194	110	127	109
21	...	278	176	186	215	207	213	151	106
22	...	189	400	328	186	190	190	181	164
23	...	342	255	214	204	202	190	152	126
24	...	178	180	278	214	202	184	254	250
25	...	255	188	214	188	201	399	210	155
26	...	178	267	265	214	239	342	250	169
27	...	297	339	214	214	186	387	249	273
28	...	311	351	207	214	213	214	178	172
29	...	178	311	238	210	206	255	178	200
30	...	178	237	315	165	272	264	221	157
31	369	298	367	257	161	202	372	197	213
32	276	188	219	270	165	197	353	235	218
33	186	259	236	219	154	281	214	291	173
34	248	202	202	220	198	197	353	203	171
35	308	339	202	266	205	226	214	239	183
36	185	309	202	329	209	400	214	193	330
37	251	267	324	193	211	264	353	275	196
38	192	259	256	251	273	209	353	180	248
39	173	178	180	270	323	195	214	278	184
40	226	178	202	203	249	253	211	180	177
41	247	178	301	307	264	341	214	198	175
42	333	373	258	312	372	278	261	185	205
43	185	250	219	328	194	213	353	341	259
44	184	378	186	279	214	279	266	256	288
45	177	462	347	280	343	187	353	226	388
46	303	277	353	251	293	175	286	187	342
47	184	221	398	190	214	261	363	157	249
48	184	301	257	279	193	191	266	135	202
49	164	184	237	329	211	177	214	137	204
50	163	184	210	214	212	188	214	135	203
51	155	184	187	213	214	208	214	134	189
52	172	183	184	276	214	186	214	121	186
Totals	4 865	11 618	11 849	12 309	11 271	11 002	11 479	9 916	8 953
Average	211	223	228	237	217	212	219	191	172

*1 000 cubic meters = 264 170 gallons = 35 314 cubic feet.

TABLE 6. — NUMBER OF WEEKS DURING WHICH THE COMBINED FLOW OF PRESENT SOURCES IS LESS FOR THE YEARS SHOWN THAN THE ESTIMATED FUTURE DEMAND.

Year.	1926.	1930.	1940.	1950.
1919	15	30	33	47
1920	2	26	37	45
1921	1	16	30	51
1922	4	21	41	50
1923	6	26	42	50
1924	17	23	35	42
1925	16	36	44	51
1926	28	37	43	50

that during a severe drought, such as occurred in 1926, a serious shortage will occur.

The Macarao River. The first source to look to for additional water was naturally the Macarao River. In October, 1926, besides the two rain gages placed on the Macarao watershed a rectangular concrete weir was built into the overflow channel at the intake, in order to measure excess water in the Macarao River not delivered to the canal. The location of this weir is shown in Fig. 2. The weir was equipped with an automatic

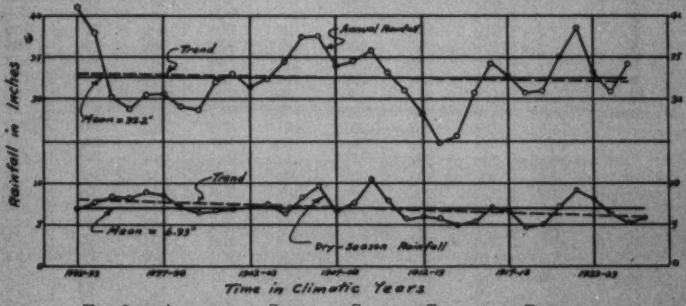

FIG. 8. — ANNUAL AND SEASONAL SECULAR CHANGES IN RAINFALL.

water-stage register with a capacity of 711.5 c.f.s. It was found that the weir was of insufficient capacity to pass the crest of the largest floods, but since these occur for such a short period of time during the total flood stage the crest discharge could be estimated with a very small error by plotting the discharge over the weir.

To determine if the Macarao River has a sufficient total flow during the average or wet years to permit a portion to be stored by means of a dam and reservoir to supply deficiencies in dry seasons, estimates of continuous flow had to be made. For this purpose the daily records of water delivered to the city for the period 1918 to 1926 inclusive, were used. To these data the excess flow during the periods of flood had to be added. No records of

flood discharge existed prior to October, 1926, when the weir was installed. It was necessary, therefore, to use this rather restricted information as a basis upon which to estimate flood flows in the previous years.

The first step was to analyze the flood data collected from October to December, 1926. Figure 9 shows the characteristics of a typical flood as

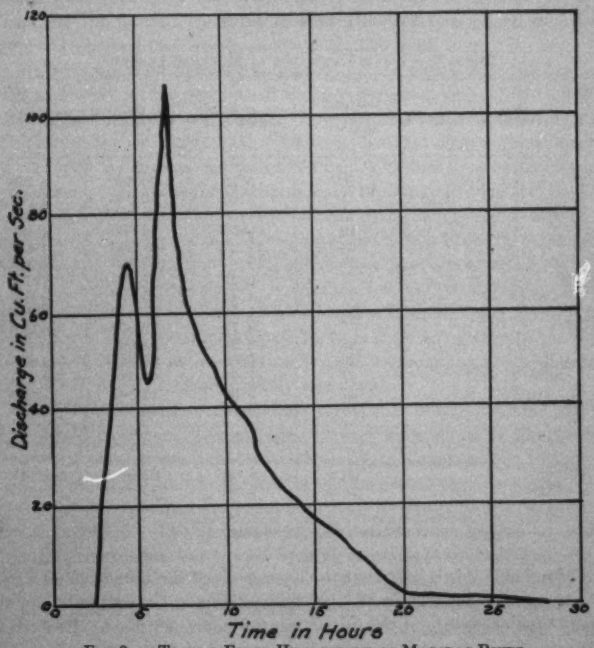

FIG. 9. — TYPICAL FLOOD HYDROGRAPH OF MACARAO RIVER.

recorded at the weir. Similar diagrams were constructed for each flood by plotting the rate of discharge during the passage of the flood. Although the crest discharge, in several instances, was greater than the capacity of the weir (711.5 c.f.s.) the duration of this large flow was always very short. Consequently any errors of extrapolation were probably less than 2 per cent. The total quantity discharged during a flood was found by measuring the area under the curves. The results are given in Table 7.

When there is a flood, the intake is usually closed during the period of greatest flow, in order to keep out of the canal the heavy load of detritus and turbidity carried by the water. The length of closure of the intake varies not only with the duration of the flood, but with the character of the water.

At times, a heavy flood will carry little turbidity and require a shorter closure of the intake than a smaller flood coming from a drainage area producing much turbidity. This is due to the local character of the storms on the Macarao drainage area. It appears reasonable to assume that notwithstanding these individual variations between magnitude of flood and length of intake closure, there is an average relation between these two factors, which may be applied without excessive error.

TABLE 7. — FLOOD DISCHARGE AT MACARAO INTAKE.

Date 1926.	Duration of Flood in Hours.	No. of Hours Intake Closed.	Total Discharge Cu. Meters.	Discharge per Hour of Intake Closure Cu. Meters.
Oct. 26	20	6.50	39 660	6 100
Oct. 27	11	5.25	10 980	2 093
Oct. 30–Nov. 2	45	20.	98 280	4 914
Nov. 5	19	6.50	28 800	4 430
Nov. 6	24	11.25	98 860	8 430
Nov. 7 and 8	41	14.	169 668	12 125
Nov. 10	27	6.25	47 880	7 675
Nov. 12 and 13	23	4.75	46 872	9 860
Nov. 16	54	11.50	73 440	6 380
Nov. 17		8.75	72 000	8 230
Dec. 1	35	8.50	55 080	6 480
Dec. 6 and 7	29	7.00	69 048	9 860
Dec. 8 and 9	47	7.25	66 384	9 155
Dec. 12	24	5.30	19 332	3 650
Dec. 16	18	6.00	46 440	7 740
Average	30	8.60	62 600	7 141
Median	25.5	7.00	55 080	7 675

NOTE: One cubic meter equals 35.314 cu. ft. or 264.2 gallons.

From Table 7 it is seen that the average flood discharge was at a rate of 7 141 cu. m. (252 220 cu. ft.) per hour of intake closure and that the average time of closure of the intake was 8.6 hours per flood. Records of the Water Department showed that in the period of 1904–1926 the average period of intake closures was 8.5 hours so that the period of flood measurements given in Table 7 appear to represent average conditions. It was assumed, therefore, that the average flood discharge per hour of intake closure was 247 240 cu. ft. (7 000 cu. meters). If any error exists in this assumption it is on the safe side as producing less water than actually flows. Moreover, even an error of 1 000 cu. m., increasing the flood discharge per hour of intake closure to 8 000 cu. m., would introduce an error of only about 2½ per cent. in the computations based on total annual flow.

To obtain the total quantity of flow during floods the recorded number of hours of closure each day was multiplied by 247 240 cu. ft. (7 000 cu. m.). This was added to the discharge through the canal at the intake for the same day. In this way the total daily flow of the Macarao River and the

average weekly discharges for the period of record shown in Table 5 were computed.

The data in Table 5 were utilized in constructing a mass curve of stream flow of the Macarao River above the intake. Naturally the curve showed that the maximum deficiency between draft and run-off on the Macarao River occurred during the drought of 1926. This drought, as indicated by the probability study of seasonal rainfall, is one that may be expected to be equalled or exceeded about once in 65 years.

Table 8 has been compiled to present (1) the capacity of the Macarao River to supply future demands if storage is created, and (2) the quantity of water required from new sources. Computations have been made under both the assumption that 53 gal. (200 liters) per cap. daily will be required, and also that the present demand of 45 gal. (170 liters) per cap. daily may be retained. The values of maximum rates of demand which the Macarao River can supply with the corresponding storage requirements are shown in columns 8 to 13 inclusive. These data were taken from the mass curve, and represent the situation during each of the past three years.

The maximum rates shown in columns 8, 9, and 10 show the ultimate capacity of the river in the respective years. If water from the Macarao River only is to be impounded here, there is little advantage in providing more than 2 000 000 cu. m. (528 million gal.) storage, as the river can fill more than this only in exceptionally wet years.

Had the storage shown in column 13 of Table 8 been available in 1926, there would have been no shortage of water on account of the drought. However, it can be seen, that with the growing demands due to increase both in population and in per capita consumption, the total flow of the Macarao in 1930 will be insufficient to provide for droughts such as occurred in 1925 and 1926. The quantities of water which must, therefore, be supplied from some other source are shown in columns 14 to 22 of Table 8.

Admirable studies for a storage project on the Macarao River were made by Dr. Oscar Zuloaga and published in the *Memorias of the Minister of Public Works*, 1923. Dr. Zuloaga proposed a dam site at La Alegria, situated about 2.8 miles above the intake. A good dam site exists at this point. A dam, 98.4 ft. high, would impound 3 110 000 cu. m. (820 million gal.) of water. The location has the serious disadvantage of having a drainage area tributary to it of only 19.4 sq. miles, two tributaries, the Quebrada Aquare and Quebrada Sabaneta being eliminated. The latter is not so important, but loss of water from the Aquare would be a serious matter.

As pointed out by Dr. Zuloaga, other good dam sites can be found, and it would be better to construct a somewhat more costly dam below the Quebrada Aquare in order to obtain the additional water. There is no doubt that adequate storage can be obtained to fulfill the conditions of columns 11 to 13 of Table 8. The chief question is how to supplement the flow of the Macarao River in order to supply the additional water required

TABLE 8.

Year.	Estimated Population.	Consumption in Litres per Capita Daily.	Total Daily Consumption.	Daily Demand in Litres per Second.	Deduction for Flow of Catuche and Cotiza.	Demand for Macarao or New Sources.	Maximum Demand Macarao River Can Supply with Storage. Litres/Second.			Storage Required for Macarao to Supply the Demands Shown in Columns 8, 9 and 10.		
							1924. (a)	1925. (b)	1926. (c)	1924. Cu. Meters.	1925. Cu. Meters.	1926. Cu. Meters.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1926	137 750	200	27 550	319	35	284	376	323	276	1 600 000	600 000	1 550 000
1926	137 750	170	23 430	271	35	236	376	323	276	1 600 000	600 000	1 550 000
1930	160 000	200	32 000	370	35	335	376	323	276	1 600 000	600 000	1 550 000
1930	160 000	170	27 200	315	35	280	376	323	276	1 600 000	600 000	1 550 000
1940	192 000	200	38 400	444	35	409	376	323	276	1 600 000	600 000	1 550 000
1940	192 000	170	32 640	378	35	343	376	323	276	1 600 000	600 000	1 550 000
1950	236 400	200	47 280	547	35	512	376	323	276	1 600 000	600 000	1 550 000
1950	236 400	170	40 188	465	..	430	...	...	...	.....	.....	.....

Year.	Demand from New Sources to Supplement Flow of Macarao.									Maximum Weekly Flow of Macarao River in		
	1924			1925.			1926.					
	Yield in Litres per Second.	Number of Weeks Required.	Total Quantity Required. Cu. Meters.	Yield in Litres per Second.	Number of Weeks Required.	Total Quantity Required. Cu. Meters.	Yield in Litres per Second.	Number of Weeks Required.	Total Quantity Required. Cu. Meters.	1924.	1925.	1926.
	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
1926	0	0	0	0	0	0	8	52	252 000	177	200	162
1926	0	0	0	0	0	0	0	0	0	...	...	...
1930	0	0	0	12	48	350 000	58	52	1 830 000	...	...	...
1930	0	0	0	0	0	0	0	0	0	...	...	...
1940	33	50	99 800	86	48	2 500 000	133	52	4 200 000	...	...	...
1940	0	0	0	20	48	58 600	67	52	2 110 000	...	...	...
1950	136	52	4 277 000	189	52	5 944 000	236	52	7 422 000	...	...	...
1950	54	52	336 000	107	52	3 365 000	154	52	4 843 000	...	...	...

(a) Dry season of a severity probably equaled or exceeded once in 4 years.
(b) Dry season of a severity probably equaled or exceeded once in 2 years.
(c) Dry season of a severity probably equaled or exceeded once in 100 years.
NOTE: 1 Cubic Meter = 35.314 cu. ft. = 264.2 gallons.

as shown by columns 14 to 22 of this table. The year 1925 represents average conditions.

A summary of data relating to rainfall and run-off is shown in Table 9. It will be observed that the minimum weekly run-off relates fairly closely to the amount of dry-season rainfall, indicating that the severity of the drought is controlled chiefly by seasonal rather than by annual rainfall. The total annual run-off in an average year is seen to be about 400 million cu. ft., whereas the demand from the Macarao source in 1930 is estimated at 380 million cu. ft. In a year, such as 1925–1926, the total annual run-off is estimated at only 328 million cu. ft.

It seems hardly worth while to go to the expense of impounding the Macarao River (in 1923 the dam was estimated by Dr. Zuloaga to cost

TABLE 9. — SUMMARY OF RAINFALL AND DISCHARGE DATA.

Climatic Year March to February.	Minimum Weekly Discharge.		Rainfall During Dry Season Inches.	Total Annual Discharge 1 000 Cu. Ft.	Average Weekly Discharge 1 000 Cu. Ft.	Rainfall in Climatic Year Inches.	Discharge in Climatic Year Inches on Drainage Area.	Per Cent. Discharge was of Rainfall.
	Month.	1 000 Cu. Ft.						
1918–1919	March	5 120	3.24	.....	....	28.83	....	....
1919–1920	May	5 440	5.40	418 400	8 060	31.21	5.24	16.8
1920–1921	March	6 040	6.21	418 500	8 060	31.18	5.24	16.8
1921–1922	August	5 580	11.10	436 500	8 420	45.28	5.47	12.1
1922–1923	March	5 120	8.15	396 500	7 700	30.46	4.96	16.3
1923–1924	March	3 742	4.96	381 500	7 350	24.91	4.76	19.1
1924–1925	May	4 418	6.98	413 000	7 950	41.96	5.16	12.3
1925–1926	March	3 496	2.15	328 400	6 320	26.88	4.14	15.3
Averages		4 875	3.88	398 800	7 700	32.49	5.00	15.4

$200 000) when with the demand likely to exist by 1935 the development would probably be inadequate. The only way in which the construction of such a dam and reservoir would be justified would be if the sources of additional water shown in columns 14–22 of Table 8 could be

(1) Diverted into the Macarao storage reservoir, or

(2) Delivered to the city independently of the Macarao supply at less cost than new sources could be developed to supplement the Macarao, either without storage or with storage on some other river.

Diversion of new sources of supply to the Macarao storage lake, if feasible, is certainly to be advised in order to utilize the available storage in the Macarao basin and the large and costly aqueduct now used to only about one fourth of its capacity. It is believed that evaporation from the water surface of the Macarao reservoir would be less than that now going on from crops. For this reason no account was made of evaporation in preparing the mass curve of run-off. Construction of the Macarao reservoir would flood out several large haciendas and thus reduce some of the present large evaporation losses. Whether or not the dam is constructed, the pur-

chase of all existing haciendas on the drainage area is strongly recommended, not only for sanitary reasons, but also because the irrigation systems and crops undoubtedly reduce considerably the amount of rainfall that finally reaches the river. The physical character of the water, furthermore, would be improved by the reduction of flood crests. The purchase and reforestation of this watershed has been recommended by nearly every engineer discussing the subject, especially by such eminent Venezuelan scientists as Drs. Jahn, Zuloaga and Jimenez. It ought by all means to be done.

Sources on the San Pedro and El Jarillo Rivers. A project has been reported by Dr. German Jimenez for the diversion to the Macarao watershed of two tributaries of the San Pedro River, shown in Fig. 1., adjoining the drainage area of the Macarao to the south. It is stated that they could be diverted by means of a canal only 4.9 miles long, and that the cost would not exceed $30 000 (in 1924). The flow is stated to have been 4.2 cu. ft. per second in April, 1909. The dry season 1908–1909 was about average, as shown by seasonal rainfall. It is probable that during the drought of 1926 the flow was reduced at least one-half. This would be sufficient to supply the deficiency shown in column 20 of Table 8 through 1940, assuming that if a drought such as 1926 were repeated, the consumption could be reduced to 45 gal. per cap. daily.

The Rio Jarillo, a small stream immediately southwest of the Macarao, has also been considered as a source which could be diverted, at least in part, to the Macarao watershed. This would require at least 3.1 miles of canal, pipe line and tunnel. It is stated that more water flows in the Rio Jarillo than in the Macarao, but no gagings have been published.

To divert each year the low-water flow of either of the above sources, would be to cause damage to irrigated land, requiring condemnation and purchase. The low-water flow, however, is not required if a dam is constructed on the Macarao River. All that would ordinarily be required, would be to divert the excess water flowing down these rivers during floods. As has been stated, there is ample storage capacity on the Macarao River to store this excess for use in Caracas during dry seasons, at least to meet the demands up to the year 1940. This project is probably the cheapest of any for obtaining additional water for Caracas. If it were decided to divert water from the San Pedro or El Jarillo rivers at elevations below the Macarao River, it is possible that sufficient flow exists to operate pumps by water power during the passage of floods. In the event of extraordinary droughts, more severe than that of 1926, it would be possible to divert also the low water of these streams, compensating irrigation interests for damage in these rare years. This would probably be cheaper than purchase of the entire water rights to these rivers.

These sources have a further advantage besides being probably the lowest in initial cost; namely, that they would be subject to the purification afforded by storage and could be passed through any purification process

installed at the Macarao intake. Any other additional sources would probably require separate purification.

Deep Wells. It has been suggested by several engineers that either a filtration gallery (Jimenez) or wells (Jahn) in the valley of the Guaire River, be investigated as sources of additional supply. The author did not favor filtration galleries for several reasons, as follows:

(1) They are difficult to locate with assurance that they will prove adequate.

(2) They are expensive to construct, and often expensive to operate, due to clogging.

(3) Once constructed, they cannot easily be deepened should the ground water level recede below the bottom.

(4) They are more liable to pollution than wells, and this is especially important in view of the heavy pollution of the surface waters near Caracas, and of the Guaire River at and below Caracas.

There seems reason to believe that considerable quantities of ground water exist in various points of the Guaire valley. The floor of the valley is composed of a thick bed of detritus whose origin is the adjacent mountains. The depth of this is not known, as no wells have penetrated through it. Surface indications are that it is gravelly in nature and highly water-bearing. The facts that so low a percentage of run-off occurs during floods, and that the streams not used largely for irrigation maintain a good flow during the months of December to March when almost no rain falls, indicates that much water is absorbed by the ground and may be recovered from it by wells. The Macarao River at the intake (drainage area 34.4 sq. miles) produced 3.88 m.g.d. in April, 1926, after three months with no rain at all. At the same time the Guaire River at El Encantado (drainage area about 285 sq. miles, including that of the Macarao and receiving the sewage from Caracas) had a flow of only 3.42 m.g.d., showing the very great influence of irrigation and other evaporation losses in the large haciendas of the Guaire valley.

It appears probable that wells 4 in. and 6 in. in diameter, sunk to a depth of 150 to 500 ft. at selected points in the Guaire valley, would encounter considerable quantities of water. The formations penetrated are such that drilling or boring could be used and the cost reduced over driven wells.

Streams Southeast of Caracas. Several projects have been considered for intercepting the flow of various streams southeast of Caracas which are tributaries of the Guaire and Guarenas rivers. To intercept these streams would require an aqueduct 27.9 miles long, constructed along the extremely rugged mountains. This would be very expensive, the cost being estimated by Jimenez in 1924 as $500 000. Jimenez also estimated the total minimum flow of the principal streams as 8.55 m.g.d. Since the total drainage area is less than that of the Macarao River above the present intake and since the regulation of flow by ground-water storage is probably less, due to the

precipitous nature of the drainage areas, it is improbable that the total flow in a dry season like that of 1926, would exceed 4.56 m.g.d. Many of these streams irrigate large areas of cane in the Guaire and Guarenas valleys, and the cost of water damages would be high. The author doubts if there is sufficient flow below the point of intake on these streams to supply irrigation requirements in average years. The project appears very costly for the amount of water that can be obtained. It should be resorted to only if investigation shows that the other surface sources are inadequate or too expensive.

To utilize these sources to supply Caracas with sufficient water to meet the demands of 1940 or 1950 would still require the construction of the storage lake on the Macarao, for only in this way could the combined sources furnish sufficient water. If this were done, the total quantity taken from both sources could be materially increased, due to the fact that during wet periods all of the run-off of the Macarao River could be stored while Caracas was being entirely supplied from the new sources of the southeast. By utilizing the available storage of the Macarao basin, the total quantity of water that could be supplied to Caracas from the two sources would probably exceed the estimated demands for 1950. By continuing the aqueduct to the southward, additional sources could be diverted, thus providing water for Caracas for many years in the future. All of this is predicated upon the construction of storage in the Macarao basin.

Quality of Water supplied to Caracas, and Suggestions as to Treatment.

The Laboratory of Sanitary Engineering of the *Sanidad Nacional* was established by the author in November, 1926, and was fully equipped to make all the physical, chemical and bacteriological tests needed to determine the characteristics of water and sewage.

Bacteriological Examinations of Macarao Source. Ten samples representing typical conditions of flow were analyzed from the Macarao River and its tributaries at or above the intake. Twenty-two tests were made of the water after it reached Caracas, representative examinations having been made of water from the aqueduct, pipe line and reservoirs. The results of these examinations may be summarized as follows:

1. In 30 of the 32 samples, the total bacteria counts exceeded 100 per cc. and all but one exceeded 300 per cc. prior to the dry season beginning in January. The maximum was 10 000 per cc. on December 22.

2. It was found by preliminary tests that *B. coli* were always confirmed in 10 cc. samples. Of the 32 tests, the presumptive tests for *B. coli* in 10 cc. was positive in 10 cc. in all but one. All but 6 of the presumptive tests were confirmed. *B. coli* was confirmed in 1 cc. in all but 6 of the 32 tests. In every case but one, where *B. coli* was confirmed, the test was also positive for organisms of fecal origin.

3. The deleterious influence of the population on the Quebrada Sabaneta does not appear to increase materially the contamination of the Macarao source.

4. The average bacterial count during the rainy season of 2 700 bacteria per cc. at the intake with *B. coli* usually confirmed, indicates serious pollution due largely to the surface wash from rains. The low counts in February in Calvario reservoir indicate a much better situation during the dry season, but even then contamination is sufficient to make the water dangerous.

5. The samples taken in Caracas from the aqueduct invariably showed a higher bacterial count than those from the pipe line. It is evident that contamination occurs in the aqueduct, and it is presumed that the heavy rains wash infected material from the hills along which the aqueduct runs and that it enters through the openings used for inspection purposes, or at the entrances to the siphons. On an average, the bacterial count of the water from the aqueduct is over twice as great as that from the pipe line.

6. The bacterial count of the water from Calvario reservoir is slightly less than the average of those of the aqueduct and pipe line, indicating a slight purification due to sedimentation and storage.

7. The water at no time of year is consistently of a bacterial character sufficiently good to pass the requirements of the United States Public Health Service, nor those of most modern cities. It is heavily polluted during at least nine months of the year, and is at all times polluted beyond a point where it can be consumed with safety.

Physical Quality. The water from the Macarao source at no time has a true color exceeding 5. It is very satisfactory in this respect. The water has no odor or objectionable taste.

During the rainy season the water in the Macarao River is highly turbid. The character of the turbidity varies markedly with the drainage area from which the floods come. Small as the total drainage area is (34.4 sq. miles) the very local nature of the rainfall causes at times floods on the Quebrada Sabaneta, for instance, when there is no flood on the Macarao River above. Floods coming from the Sabaneta drainage area carry a very high and very objectionable turbidity. This is in the form of very finely divided particles that settle very slowly. Floods from the other drainage areas carry a more sandy material in suspension, which settles rapidly, and the water quickly regains its clarity. When the water becomes turbid during floods, the intake gate is closed, all water in the river being wasted. The number of closures of the intake from this reason for the years 1904–1926 inclusive, averaged 274 hours per year.

The difference in the character of the turbidity of the floods is shown by the fact that on November 6, a flood lasting 24 hours required 11.25 hours of closure, whereas on December 12, a flood of the same length required only 5.3 hours of closure.

Samples of the flood waters were taken under several conditions of flow.

The maximum turbidity was observed during the flood of December 1, and amounted to 20 000 p.p.m. The water carried 5.42 per cent. of silt by volume. Other floods of equal maximum discharge had turbidities of not more than 8 000 to 10 000 p.p.m. Moderate to small floods have turbidities of 100 to 500 p.p.m. Very large quantities of sand, gravel, and boulders are carried into the intake by moderately large floods, and the cost of removing these from the canal and settling basins is considerable. The water, as delivered to the city, practically never has turbidity, due to the practice of closing the intake during the crests of floods and of using settling basins in the canal and aqueduct. There are settling basins before each of the siphons in the aqueduct, and it is quite possible that the additional contamination of aqueduct water is due to pollution introduced during cleaning.

Chemical Quality. No chemical ingredients injurious to health are found in the water. The water is quite hard, having a total hardness of 120 to 125 p.p.m. The alkalinity to methyl orange is 110 p.p.m.

Acidity is due wholly to free CO_2 and is very small, ranging from 2 to 5 p.p.m. As delivered to consumers in the city, the water often has no free CO_2. The chlorides are low, averaging about 2 p.p.m. As would be expected from the hardness, the hydrogen-ion concentration is low, the pH value varying from 8 to 8.3. On the whole the water is of excellent chemical quality except for its hardness, which makes it unsuitable for modern boiler use, unsatisfactory for laundry purposes, and very difficult to coagulate with aluminium sulphate.

Treatment Processes Recommended. The only treatment of the Macarao water required for health or aesthetic reasons is the removal of bacteria and turbidity. Both might be considerably reduced after a period of years by the expropriation and reforestation of the watershed. Chance contamination and turbidity will always remain. In the event that a storage reservoir is constructed upon the Macarao basin, as recommended, a large reduction in bacteria might be expected and an almost total elimination of the turbidity in water supplied the city. The turbidity ordinarily is almost wholly removed by settling for a period of 12 to 24 hours, and much more than this would be available in a reservoir. The reservoir, however, would tend to silt up rapidly, and conservation measures should, in any event, be taken to control erosion and promote reforestation.

If the entire drainage area of the Macarao above the intake were purchased by the Government, wholly depopulated and reforested, it is probable that the bacteriological quality of the water would be sufficiently good (especially if the storage lake was built) so that no filtration would be necessary, and sterilization by chlorine would be ample protection. Moreover, the lake would itself flood out some of the most objectionable cultivated areas and would be located above the Quebrada Sabaneta which contains the greatest population on its drainage area and has the worst physical quality of water. The cost of construction of the reservoir would in all

probability be less than the purchase of the entire present watershed and would have many advantages other than that of producing a more acceptable water.

It was recommended that sterilization of the Macarao River at the intake by means of liquid chlorine be provided at once. This would produce a reasonably satisfactory water for delivery to points between the intake and Caracas. Secondary chlorination plants should be installed at the Guarataro and Calvario reservoirs. With present water quality from Macarao, a bacteriologically safe supply could be delivered to the city in this way, if daily bacteriological and chlorine-control tests were made.

In the *Memoria de Obras Publicas* for 1915, there is presented the report of a commission of scientific men, appointed by Dr. Centeno Grau, to investigate the subject of a filtration plant for the Macarao supply. This commission recommended the adoption of the slow sand process of filtration which does not need any chemicals for its operation. With this recommendation the present writer was in entire agreement.

For the Macarao supply, a slow sand filter plant was recommended for the following reasons:

1. The first cost would probably not exceed that of a rapid sand plant.

2. The operation would be much simpler and cheaper. Experiments made with Macarao water indicate that it is very difficult to coagulate with aluminium sulphate. As much as 4 grains per gal. of aluminium sulphate are required to produce an appreciable floc. This is equivalent to 568 lbs. per million gal. The present average quantity supplied by the Macarao source is about 4.36 m.g.d., which would require an alum dosage of about 2 480 lbs. per day. This would be very costly and require skilled operation, conditions that would be aggravated as more adequate supply was made available.

The high alkalinity of the water with almost total absence of free CO_2 and the consequent high pH of 8.0 to 8.3 is the reason for the large dosage of alum required. Best coagulation of this water occurs at a pH of 6.2 to 6.6. Tests were made utilizing sulphuric acid to reduce the pH prior to adding the alum. It was found that this procedure would prove more expensive than using alum alone. It is possible that further tests utilizing alum in combination with acids and alkalies would indicate methods of producing a somewhat more economical dosage, but it is certain that large amounts of chemicals would be needed.

3. There are on the average not more than 274 hours per year when the intake has to be closed on account of excessive turbidity. This is only 3 per cent. of the time. With the proposed reservoir, the turbidity of water delivered to the intake would be greatly reduced. Since the principal reason for using the rapid sand process is to be able to filter a water of high turbidity or color, there appears no reason why slow sand filters should not operate satisfactorily even with the present methods of turbidity removal.

4. The cost of operation and the amount of skilled attention needed with slow sand filters would be much less than with rapid sand filters.

5. The percentage removal of bacteria by slow sand filters is at least equal to that of rapid sand filters.

6. For the character of water supplied from any of the present Caracas sources the slow sand filter appears from every consideration to be the most economical and satisfactory to be adopted.

It was the opinion of the author that if the Macarao reservoir were built, no filters would be required. Chlorination of the water should be applied whether or not filters are built. Considering the combined advantages of the Macarao River reservoir in (1) producing storage and (2) removing turbidity and bacteria, it appears that it would be far more economical to construct the reservoir than to build a filtration plant, and that an equally good water could be obtained if double chlorination were applied; i.e. at the exit from reservoir at Macarao and again on leaving the city reservoirs.

Bacteriological Examinations of the Catuche and Cotiza Sources. The results of 23 bacteriological tests on water from the Catuche and Cotiza sources indicated that:

1. The water is of much better bacterial quality than that from the Macarao River, the average total counts being less than one-third those from Macarao.

2. Nevertheless the water is not of satisfactory quality, having excessively high bacterial counts and *B. coli* of fecal origin being confirmed in all but one of both the 10 cc. and 1 cc. samples. Only two of the samples from the Polvorin tanks into which these waters are delivered did not show confirmed *B. coli* of fecal origin.

3. The water from the Cotiza source has in every case a markedly lower total bacterial count than that from the Catuche source.

4. In several instances the water from the Polvorin tank contains a much higher bacterial count than that from either of the two sources on the same day. This indicates contamination from substances getting into the tanks. This is not surprising since the tanks are in the midst of a populated region, are small, uncovered and exposed to contamination.

Chemical and Physical Examinations. Typical tests on January 31, 1927, of the two sources gave the following results:

	Catuche. p.p.m.	Cotiza. p.p.m.
Turbidity	0	0
Color	0	0
Odor	0	0
Total Hardness ($CaCO_3$)	123	54.3
Total Alkalinity	114	....
Chlorides	6	....

It appears that the chemical and physical character of the Catuche source is very similar to that from Macarao. The Cotiza water is markedly better only in having a much lower hardness and alkalinity. However,

the Cotiza source supplied only about 6 to 7 per cent. of the total quantity delivered to the city, and consequently its chemical ingredients are of small importance.

Recommendations for Treatment. The water from these sources is never sufficiently turbid to require wasting. The Polvorin tanks are of sufficient capacity to effect all sedimentation necessary. The total drainage areas of these two sources amounts only to 3.8 sq. miles, very little of which is in cultivation. If this drainage area were purchased by the Government, depopulated, and reforested, it would undoubtedly be possible to deliver a water of satisfactory quality by merely chlorinating the effluent from the Polvorin tanks providing these tanks were covered.

Distribution System.

A word concerning the distribution system in the city of Caracas may be of interest. Main pipes are from 6 to 12 in. in diameter. Ordinarily street mains are 2 to 6 in. in diameter. Larger mains are not required since there are practically no fire services, nor is any such provision for use of water in fires needed as is the case in the United States. Buildings are all of fire-resistant materials, and a fire is nearly always easily confined to the structure where it starts. Two modern chemical engines would give entirely adequate fire protection to this city of 135 000 people.

A unique factor in the design and operation of the distribution system is the practice of delivering water to houses only for 2 or 3 hours per day. Each house must have storage tanks sufficient to hold a day's supply. This system makes possible reduced sizes and reduced pressures in street piping thereby reducing first cost and leakage. It is also conducive to curtailment of waste in houses. It is certainly a most inconvenient system for the householder who is a little generous in his use of water and exhausts his storage tanks before the water is turned on in the morning. Incidentally it adds tremendously to the work of the sanitary inspectors to see that all house tanks are proof against mosquito breeding.

Water delivered to houses or buildings is measured by being passed through an orifice set in the service pipe. Each such orifice constitutes a "water right" for which a flat rate is paid annually. To insure equality of service the pressures all over the city must be maintained approximately equal at all services. In consequence the Reports of the Department of Public Works are full of the most elaborate tables calculating proper pipe-sizes to give equal pressure at all services in the distribution system covering a city located on mountain slopes and differing by 500 ft. in elevation. Many streets have two or more pipes, and the daily manipulation of countless valves all over the city to provide the 2-hour period of service has resulted in a most complicated operating schedule.

The piping system is old and there are many corroded mains. In certain instances main pipes are broken and corroded service lines are common. Where soil pollution exists, as is not uncommon from leaky

FIG. 10. — REGIONAL MAP OF CARACAS AND VICINITY.

sewers, pollution may find its way directly into the water mains when the pressure is turned off each day. As a consequence of known infection, very few people drink the water without boiling it.

Caracas is probably typical of many South American cities, and represents the best practice in Venezuela. There is a great potential opportunity for American engineers in the design and construction of modern water-supply systems for such cities, but progress will be slow due to indifference on the part of many of the politicians, great waste of time in negotiating contracts, a suspicion of American motives and political conditions. Very few South American engineers receive their training in the United States, and water-works practice is founded largely upon theory advanced in French textbooks. Undoubtedly a field of endeavor presenting great mutual advantages to South Americans and to engineers and contractors from the United States will eventually develop in the water-works field in these countries.

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Discussion.

Allen Hazen.* I want to say just one word. We go to the cities of our Spanish neighbors and visit their water-works systems, which are not the same as ours, and we think they are not as good as ours in many ways, and probably we are right, but there is one thing that the author spoke of which I think may be further emphasized. I know that what he says is true of other Spanish cities. He said they did not have any fire service, and they do not need any. They build their cities fireproof or practically so, and they do not have any trouble with fires. There are some things that we can learn from our southern neighbors.

L. H. Enslow.† In connection with matters of sanitation in South American countries, I think the people of New England might be interested

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in a situation found to exist at Bogota, Colombia, in 1920. Mr. Geo. C. Bunker, Sanitary Engineer of the Panama Canal, was called to Bogota in consultation in connection with the water supply and prevalence of typhoid fever. This was the situation: The water supply was taken untreated from the river on the outskirts of Bogota and periodically, at the beginning of the rainy or "wet" season, typhoid and dysentery were plentiful, accompanied by an extremely high death rate.

The direct cause of these water-borne diseases was found to be: Above the city the river took a sharp bend around a high and steep hill which had been selected as a proper place to erect a shrine. Each year during the "dry" season pilgrimages were made by thousands of people to this shrine near which there were no provisions for caring for defecation. Consequently the people made use of the hillside away from the city and directly above the river. Nothing happened until the season of rainfall and the very quick run-off mentioned by Mr. Saville set in. The use of the untreated water from a point downstream completes the story of the yearly disaster at Bogota from typhoid and dysentery.

RICHARD G. TYLER.* There is an item of interest to which I think attention has not been called, in regard to water supplies in the arid and semi-arid areas such as the one described by Professor Saville. That is, that in trying to provide ample storage capacity in a reservoir to take care of silting-up and still give it a reasonable life, a fairly large water surface may be necessitated with correspondingly large evaporation losses. The engineer is here between the devil and the deep blue sea. He must build his reservoir large so that it will provide a safe margin of available storage after some years of silting-up, and yet not have the water surface too large a percentage of the total drainage area. Where rainfall and run-off are low, evaporation is frequently very high and those reservoir sites are most desirable which have their volume distributed vertically rather than horizontally. This is the reverse of the requirements of a reservoir for power development. As an example, where the annual rainfall is 30 inches, the average coefficient of run-off may be as low as 10 per cent. The gross delivery of the watershed is then one-quarter acre foot per acre per year. Assuming an evaporation of 60 in. per year and a reservoir with water surface equal to 5 per cent. of the total drainage area, the net yield would be zero. The speaker has had just such a situation to contend with in the southwest and it is a common one in semi-arid areas. The topography of the reservoir site is extremely important, therefore, in such cases.

CHARLES F. BROOKS.† Prof. Thorndike Saville has described how the air from which the rains that water Caracas and vicinity are precipitated comes from the east and southeast some distance over the land before reaching Caracas. And he indicates the smaller rainfall of the Caracas region than that nearer the sea to the east, in spite of the fact that the Car-

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acas region is 3 000 to 4 000 ft. above sea level. The reduction in rainfall as the air flows inland is ascribed to a more rapid convectional drying than ascensional stimulation of rainfall. In a manuscript which Mr. Robert E. Horton permitted the writer to see some years ago, the relation between convectional exhaustion and ascensional stimulation of rainfall was worked out to a nicety. For increasing rainfall towards the interior the slope must be great enough to make rainfall by forced ascent greater than the reduction of rainfall owing to the convectionally-decreasing vapor content of the air. From the sea to Caracas the slope is not sufficient for increasing the rainfall in this low latitude, nor for even holding it to nearly its seaside figure. A new map of the average annual precipitation of South America by Gooze* and Jones,* shows the eastern seacoast to have an annual precipitation of slightly over 40 in., while Caracas has 32. In the valley above Caracas the up-slope factor favoring rainfall exceeds the exhaustion factor, and the rainfall increases to over 40 in., its seaside value. It is possible, however, that vapor from the north coast, entering through an important gap in the mountains is a factor favoring more rainfall above Caracas.

The writer had an opportunity on March 11, 1924, to compare the absolute humidity of the air from the southeast, up the valley, and that from the northwest, pouring through a gap in the coast range. The following table gives the data obtained with a sling psychrometer and later reduced with U. S. Weather Bureau psychrometric tables:

ABSOLUTE HUMIDITY AT CARACAS, MARCH 11, 1924.

Place.	Hour.	Dry of Bulb. °F.	Wet of Bulb. °F.	Dewpoint °F.	Relative Humidity Per Cent.	Absolute Humidity Inches Vapor Pressure.
Country Club	11:15 A.M.	82.1	66.9	59	46	0.50
Obs. Cajigal	12:00 Noon	82.5	67.0	59.5	46	0.51
(S. slope of the observatory hill)	(12:10 P.M.)	(97.0)	(74.5)	(65)	(35)	(0.62)
Near center of city	1:10 P.M.	75.5	71.0	69.5	81	0.72
Near center of city	1:30 P.M.	80	72	69	69	0.71
Near center of city	1:35 P.M.	79	71	68	68	0.68

During the morning and till 1 p.m. the southeast wind was blowing, and the skies were dotted with cumulus clouds whose bases were 9 000 to 9 500 ft. above sea level (as shown by their touching the highest peak). At 1 p.m. the sea breeze from the north coast reached in through the gap and suddenly refreshed Caracas, though the effect was short-lived for the humidity was made higher. This one comparison shows that the air from the southeast had about 30 per cent. less water vapor in a unit of volume than did the air from the northwest. This suggests that if the northerly sea breeze

*Charles Gooze and Clarence F. Jones, "The Seasonal Distribution of Rainfall in South America," *Bull. Geogr. Soc. of Philadelphia*, Apr., 1928, vol. 26, pp. 93–115, 5 maps. (Reprints may be had from C. F. Brooks, Clark Univ., Worcester, Mass., for 15c.)

may be taken to represent approximately the dry season condition of the air, (if raised directly to the altitude of Caracas) as it comes ashore at the mouth of the eastward valley in which Caracas is located, then the air at the surface loses some 30 per cent. of its vapor through mixing and perhaps also precipitation due to convection in the course of its horizontal movement.

The north coast of Venezuela has light rainfall for a tropical coast. This characteristic was noted at the Nashville meeting of the American Meteorological Society, and the following points were offered in this connection by the writer:* "Dr. Charles F. Brooks told of observing cool coastal water and local calm weather along the north coast of South America in March, 1924. Near the Margarita Islands, east of La Guaira, the sea temperature was 72° F. while farther east, near the Dragon's Mouths, between Trinidad and the mainland of South America, the sea temperature fell to 69.5° F. This coolness must have been due to upwelling owing to the seaward motion of the surface layers of water under the combined effect of the easterly wind and the earth's rotation. The warm current setting west-northwestward through the Dragon's Mouths and a few miles offshore had a temperature of 79° to 80° F. The trade winds paralleled the shore, and at a moderate height cloud motions from a southeasterly direction revealed a general movement of the air seaward. While this movement of the winds would be adverse to rainfall, the cooler and drier air over the cool coastal water would also favor the scanty rainfall observed there."

*Bull. Am. Meteorological Soc., Feb., 1928, vol. 9, p. 44.

THE DESIGN AND EQUIPMENT OF WATER-WORKS LABORATORIES.

BY MELVILLE C. WHIPPLE.*

The chemical and biological laboratory occupies an important place in the organization of water-works departments. It furnishes day to day evidence of the quality of water distributed to consumers; it gives notice of impending changes in raw water sources; and it provides the only reliable service for the operation and control of purification processes. Broadly considered, the laboratory constitutes a form of insurance that is preventive, not compensatory in its action and is entered into for protection against losses to the water works and to its patrons.

In order properly to serve the appointed rôle, the laboratory must have had good design and equipment and must be in the hands of qualified operators. Deficiencies in either direction are serious. It is a matter of common observation that the physical needs are too often left to the devices of those who least appreciate them.

This paper aims to suggest to the uninitiated some of the desirable features and necessary equipment of a water-works laboratory; there is also the hope that the material here presented may prove helpful to others as a reference guide in making decisions upon matters of detail.

Matters of Policy for Early Decision.

In connection with the establishment of the laboratory certain questions of policy arise that should receive consideration and be given decision before others. This will prevent subsequent confusion and misunderstanding.

Activities of the Laboratory. The character and extent of the work to be done is a matter for early determination. Some laboratories function merely for the benefit of purification works and the water department. Others are required to do testing for other departments as those of sewers, roads and streets, health and engineering departments. The ramifications of activity need to be understood. Likewise, thought should be given to the extent of future increase in work, whether it will take place slowly or rapidly. There should, also, be agreement as to the use of facilities for consulting work from the outside.

Available Funds. Those in responsible charge should know the amount of funds available for all fixed and permanent charges, such as interest, if any, salaries and possibly rent. A sum should be determined upon for

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initial equipment of fixtures and equipment and an approximation should be made of the annual cost of replacements and additions.

General Location of Laboratory. If the laboratory is designed to serve, among other things, for the control and operation of a purification works there is only one location for it, namely at the works. Under other circumstances it should be centrally located for the needs of the service it renders. This may be in a departmental building, at municipal headquarters, or less desirably in rented quarters. The item of location will influence the necessary funds for fixed charges.

Personnel. Early decision needs to be made in regard to the number and balance of technical workers. A small laboratory usually operates with one trained analyst who must be versed in all phases of the work to be done. If there are two or more workers, the one in charge must be chosen not only for his professional ability, but also for his administrative capacity. Proper functioning of the laboratory demands that the man in charge shall be of higher grade than the assistants, and he should be given a salary that is higher in proportion to his ability. Arrangements should guard against a top-heavy personnel. The whole question of personnel has to be decided from the funds available and the character of the service expected.

A laboratory "diener" should be provided to take care of cleaning and odd jobs. In a busy laboratory he may be a full-time employee, otherwise he may spend part of his time as a janitor or plant helper.

Position in the Scheme of Administration. There is necessity for a harmonious arrangement and plain understanding regarding the responsibilities of the laboratory and the channels through which must go its information and recommendations. The chemist in charge transmits reports and data, but working rules should prescribe whether these shall go to a departmental head or to those who are more directly concerned with them. This is particularly important where there is interlocking responsibility for the operation of a plant and where the laboratory is serving more than one municipal department.

When purification is one of the activities of a water works, the chemist and the plant operating-force should work in close contact and harmony, and information should follow a short circuit in order that its full value may be realized. This gives the laboratory responsibility, pride and prestige. Personnel should be chosen with regard to its ability to live up to these desirable ends.

The demands of an enlightened and fastidious public for clean water have become so insistent and the proper control of purification processes so complex that the operation of the latter without scientific guidance is fraught with irritation and hazard. The day of laboratory control is established. To be without it, is to harken back to times of uncertainty and empiricism. More distressing than the examples of those water works that are carrying on in the old way without modern facilities for gaining

information are those that have initiated a system of laboratory control and then, through neglect, indifference or inability to command support, have allowed the equipment at hand to deteriorate, or the staff to degenerate, or have allowed both to cease functioning. Once established, a good laboratory should always justify its existence.

Selection and Layout of Space.

Selection of the portion of a building to be used for laboratory purposes should be made with several requirements in mind. Most important are the following:

1. The space should give easy accessibility to offices connected with the laboratory and to important parts of the plant.

2. Outside light should be abundant and of a quality suitable for colorimetric tests. Upper floors and north and east exposure provide the best light. The lower window panes should be single and not cut up with small sashes, especially in rooms for microscopic work. Windows should come down to the height of bench tops and not be 5 or 6 ft. above the floor. Skylights supplement window illumination, but are not desirable except when light is inadequate.

3. The rooms should not be subjected to extremes of heat and cold that make occupancy uncomfortable and interfere with the operation of sensitive apparatus, such as balances and incubators.

4. A location influenced by dust, noise or vibration is not suitable for laboratory purposes. Street exposures and proximity to pumps and heavy machinery should be avoided.

5. The amount of space that is necessary will be largely dictated by the amount of work to be done and the number of persons employed. It is possible to have too much space; this results in inconvenience and unnecessary travel. A certain minimum of space is required to prevent crowding and to make easy the conduct of work even in a small way. A room 12 ft. x 18 ft. is large enough for the routine of one worker if there is additional space for storage and certain general operations, such as cleaning and sterilization.

Where there are two analysts, there may be two rooms, or the principal work can be conducted in one room not smaller than 15 ft. x 22 ft., with smaller rooms for storage, preparation and incubation. Preparation of media, cleaning of glassware, etc., can be carried out in a room 12 ft. x 14 ft. in dimension. Incubation and culture work requires a room about 10 ft. x 10 ft. The smaller rooms should be easily accessible from the main room.

If routine duties are divided on the basis of chemical and biological tests, the best arrangement is provided by a separate room for each. If one man carries out all the analytical work, his activities are better concentrated in one main room that is equipped for all except general operations.

In conjunction with and adjacent to every laboratory there should be

office room to provide for desk work, reading, conferences and filing of plans and records. This should be not smaller than 10 ft. x 12 ft. and larger if necessary. Office and laboratory should not be combined in one large room. Stimulus and refreshment are to be derived from occasionally drawing away from the scene of routine activities. The office should contain as large a number of useful technical books and periodicals as available funds will provide for. A list of these has been suggested and will be found at the end of this paper.

There is one practice often observed in water-works laboratories that should not be condoned; that is the storage of tools, fittings and mechanical appliances that are a part of shop equipment. Laboratory space is intended for technical work; there should not be interruption and annoyance from persons who have no interests or responsibilities there.

Plans and Specifications. From the foregoing it is evident that considerable care should be given to the selection and layout of space. In all new structures that are to house laboratories, these matters should be incorporated in the plans and specifications and not left to a hit-or-miss development, if satisfactory arrangements are to be secured.

It is well to have both floor plans and elevations showing all possible details. These include windows, partitions, sinks, radiators, benches, cases and all fixed equipment. To facilitate the work of mechanics, outlets should be shown for water, light, gas, power and drains.

Fixtures and Special Features.

Cabinet Work. A large item in the initial cost of equipping laboratory space is that for permanent fixtures such as cases, benches, drawers and cupboards. The number of these will vary with the size of the laboratory and the extent of its work. The character of the materials used will be dictated by the funds available for the purpose and by the appearance that it is desired to present. Uniformity of exposed wood materials is desirable, at least for each room.

The most durable and likewise the most expensive material for cabinet work is hard wood, maple or oak, finished in the natural grain of the wood. Soft woods with painted surfaces are least durable; they are easily marred and quickly stained. A compromise material, and one that is not as expensive as hard wood, is Carolina pine. When finished in the natural grain, it presents a pleasing appearance, is not easily soiled, mellows in color with age and contrasts well with walls and other exposed surfaces. The cost of cabinet work is usually 50 to 75 per cent. of that for apparatus and chemicals.

Cases for Chemicals and Glassware. Cases for the storage of chemicals and glassware are best made with adjustable 10-in. shelves and protected with glass doors. Their overall height should not exceed 8 or 9 ft. The capacity is increased by extending them to the floor, or they may be brought

down to bench height and equipped beneath with cupboards 20 to 24 in. deep. Sliding doors are more convenient than hinged doors and offer no obstruction to room space. There should be some open shelves above benches to allow for ready use of solutions and small apparatus.

Benches and Tables. Benches may be placed along the walls, preferably along those having windows. Their height should be not less than 36 in. and better 38 in. for the average worker. At intervals, sections of drawers and occasional cupboards may be placed to advantage under the benches. These ought not to be in front of windows or where there is constant use of the benches, for they interfere with foot room and the use of laboratory stools. Drawer and cupboard sections may be from 24 in. to 30 in. wide and as deep as the bench top is wide, allowing a setback of about 2 in. from the front edge of the bench for working comfort.

The working surface of benches may be finished in a variety of ways. White materials, such as 3 in. x 6 in. tile and milk-glass slabs present a "showy" appearance and are easily kept clean. They have the disadvantage of cracking when exposed to high heat or to strains from settlement of floors and are very destructive upon glassware. The dazzling reflection of light from them is trying to the eyes. Also, they are expensive. Tile is best laid in a layer of white lead after being coated on the under side with a layer of shellac to prevent absorption of oil.

Soapstone tops are not as hard as glass and not as easily cracked, but they are expensive and difficult to keep clean. Aniline-black wooden tops are to be recommended for their comparative cheapness, durability, ease of cleaning and lack of reflection. They should be made of maple or Carolina pine and kept free of grease or paint until the following formula is applied. The same applies to the back rail at the bench tops, where used.

Aniline-Black Formula for Bench Tops.

Solution No. 1:	Potassium chlorate	125 grams
	Cupric sulphate	125 grams
	Water	1 000 cc.
Solution No. 2:	Aniline Oil	120 cc.
	Hydrochloric Acid	180 cc.
	or	
	Aniline Hydrochloride	150 grams
	Water	1 000 cc.

NOTE: Apply both solutions hot. Apply two coats of No. 1 at least 12 hours apart. When dry apply two coats of No. 2. When these are dry apply one coat of raw linseed oil. Do not let the oil pool on the wood or it will become gummy. Rub it in with a cloth after it has stood for a short time. When the oil is dry wash down with strong, hot soapsuds. An ebony black finish will result. Occasional oil and soap treatment insures a glossy black surface and keeps the pores of the wood filled. This preparation is not a paint, but a stain, and penetrates beneath the exterior of the wood.

In water laboratories it is convenient to have a white-top table in the center of the room, 30 to 36 in. wide, for the reception and inspection of samples. It improves the appearance of the room and is also useful for

bacteriological and other work. The table may be equipped with gas, water and a sink.

Floors and Floor Covering. Floors of wood are easy to walk and stand upon but they accumulate dust and other dirt in the cracks. When left bare they should be oiled. Tile floors are often uneven, difficult to clean and hard. Cement floors are the worst of all unless filled or painted to keep down dust and make cleaning easy of accomplishment. Even then, they are tiring to travel over. The latter objection can be met by the use of rubber matting that covers all spaces between fixtures. The ideal floor, whether of wood or cement, is one covered with linoleum or cork matting in a plain, neutral color.

Partitions, Painting of Walls. Partitions between connecting rooms, when erected after construction of a building, are best made of plaster, but expense may be saved in dividing off small rooms if composition board, "Sheet Rock" or similar material is used. It is not, however, as sound-proof as plaster. Where partitions interfere with illumination, the light can be increased by placing panes of glass in the top of the partition. Ribbed glass is better than clear glass; it cuts off the view and gives greater diffusion of light.

Flat colors, either white or cream, should be used on walls and ceilings. Either oil or water paints may be used. Oil paint can be cleansed or renewed without taking off the old coat. Lead pigments are not satisfactory, due to their discoloration by sulphurous gases. Walls and ceilings should serve to supplement window illumination by reflection. To this end they must be light-tinted in order not to interfere with colorimetric determinations. Their surfaces, if light, offer a pleasing contrast to woodwork and fixtures. A dado some 4 or 5 ft. in height and of a dark, neutral color, reduces the apparent soiling of lower parts of walls.

Artificial Lighting. Artificial overhead lighting should be of the indirect variety in order to provide proper dispersion. Such a system usually does not provide sufficient illumination for night work at benches, owing to the shadow cast by the worker. Outlets over the benches or in the wall are necessary. Wall outlets are further useful for microscopical lighting, counting of bacteria, etc.

Heating Arrangements. All laboratory rooms demand ample heating facilities in order to provide uniform temperature and to guard against freezing of pipes and solutions along exposed walls. The science of heating and ventilation dictates the placement of radiators near windows. This sometimes uses up valuable space and results in working positions at benches being uncomfortably hot. Preliminary studies should include the most advantageous location of heating units.

Distribution of Water, Gas and Electric Outlets. Plans should include the location of all water, gas and electric outlets and sink drains. A liberal but not a useless number of these should be provided, and they should be placed at advantageous points.

Water outlets are best fitted with pantry cocks having hose-bibs to prevent splashing. Nickel finish is of better appearance and more resistant to corrosion than brass. Gas cocks should have lever handles and should be kept at the rear of bench tops. Electric outlets are best placed in, or just above, the back rail of benches.

Sinks. Sinks are of many kinds and are much used in the routine of the laboratory. For general cleaning operations there is no better material than soapstone. Sinks of any desired size can be made from it. There should be one large, deep sink in a laboratory to make possible the washing of large containers, burettes and pipettes. The depth should be not less than 10 in. and the horizontal dimensions 20 in. x 40 in., or in that proportion.

Enamel sinks are suitable for smaller sizes and where dyes and strong solutions do not come in contact with them. Hard usage causes them to crack and scale. Copper-lined wooden sinks are sometimes useful and are fairly cheap. If kept covered with asphaltum paint they are very durable and have the advantage of not being hard upon breakable apparatus.

Hoods. An enclosed hood with either natural or forced ventilation is necessary in large laboratories to take care of strong fumes. The frame and sash may be of metal fitted with wire-glass windows, or to save cost, wood may be used instead of metal and clear glass instead of wire-glass. The inside should be lined with fire- and fume-resisting material, such as asbestos board.

Good natural draft is sufficient for most operations, but heavy vapors require forced ventilation by means of a fan. A down-draft removes these easier than an up-draft and with the likelihood of less leakage into the room.

The elimination of heat from sterilizers, steam baths and the like, is advantageously accomplished by means of an open or apron type of hood placed above the apparatus and communicating to a flue or a ventilator on the roof.

Hot Water. Hot water is a necessity and should be supplied from the tap. This may be obtained by indirect heating from the central heating plant during the cold season. At other times, if hot water is not furnished to other parts of the building, the laboratory should maintain a small instantaneous heater.

Gas. Distant locations sometimes make it impossible to obtain gas from community supplies. In this event the best solution is the use of illuminating gas from pressure cylinders. These give more satisfactory results than generators or gasoline outfits.

Equipment of Apparatus and Chemicals.

The amount of initial apparatus and chemicals to be purchased will be governed by the scale of intended operations, by the sum of money immediately available and by the prospect of liberal future additions. In

no case should the policy be followed of meagerly equipping at the start. It is a better and a safer course to equip adequately. The laboratory can then function properly and live up to what is expected from it.

There is often oversight of the matter of replacements and additions. Breakage, lapse of usefulness, the use of chemicals and unexpected activities demand that renewals and enlargement of stock be dealt with in a generous fashion. There is no denying the fact that laboratories are expensive, but at the same time necessary auxiliaries of most water works.

Equipment Costs. There are so many factors operating to modify the total sum to be invested in scientific equipment that it is difficult to give a close estimate of the amount to be set aside for this purpose. The scale of market prices, the availability of funds, the size and activities of the laboratory, all influence the initial expenditure.

A small laboratory serving a plant or water works with an output up to 4 or 5 m.g.d. will require from $700 to $1 200 for necessary equipment. One such laboratory actually expended in 1920 for apparatus and chemicals $800. For other plants up to about 30 m.g.d. a fair estimate of initial expenditure is $1 500 to $2 500. The Cambridge Water Purification Works that has a nominal capacity of 14 m.g.d. made in 1923 an initial outlay of $1 500 for equipment. The list included very few items except absolute essentials. Large water works may expend $2 500–$4 000 for their laboratory equipment.

Selection of Equipment. The selection of apparatus and chemicals is a task that is time-consuming and one which requires discretion and a knowledge of scientific matters. The logical person to undertake it is the man who will later be in charge of the laboratory. A suggested procedure for selection of equipment is that which follows:

First, visit other laboratories with the object of getting ideas from the practice and experience of others engaged in similar work. New devices and new uses of familiar apparatus will likely be found. Such visits are even more profitable if made prior to the design and layout of permanent fixtures. They then contribute ideas on the utilization of space to be alloted for the new laboratory. Trips to the showrooms of apparatus dealers, if these are not too distant, are generally worth while in order to gain acquaintance with newer and special items of equipment.

Second, obtain from representative dealers copies of their general catalogues that contain illustrations and descriptions of all forms of apparatus.

Third, go through one or more of these catalogues page by page, listing every article it is desired to purchase. Write down the catalogue number of each article and indicate the size, number wanted and any special features that are necessary for identification. The list price may also be included in order to approximate the total cost of the complete order. A numbered, alphabetical list of all articles is obtained by this method; its form is useful for reference and for dealers' estimates.

Fourth, submit the list of apparatus and chemicals to several reputable

firms for bids, advising them of cash discounts or any other financial procedures that are enforced by your department or municipality. In large cities the purchasing agent may be the individual to obtain these bids and to act upon them.

The prices for standard equipment do not vary greatly among large dealers and it has been the writer's experience that bids on large diversified orders will not differ by large amounts. In one instance three firms submitted estimates as follows:

Low bidder	$1 376.89 goods delivered
Second bidder	1 452.56 goods delivered
High bidder	1 491.39 goods f.o.b. point of shipment.

There were some substitutions, but not many, in the order as bid upon by the three firms.

Fifth, place the order with the dealer who gives promise of a fair price and good service. Promptness of delivery and willingness to exchange unsatisfactory articles are usually the principal elements of good service. Do not split the order among several dealers unless there is some special reason for doing so. The larger the size of the order given the greater will be the desire of the recipient to render favors in return.

Details of Equipment.

Personal opinion and the needs of any particular laboratory will determine the individual items in any list of equipment. Therefore it is not possible to suggest such a list that can be used *in toto* under all circumstances. The list of apparatus and chemicals that is given here will be found to satisfy the needs of the average water-works laboratory that is controlling the output of a 10 to 15 million gal. purification works.

In order to cut down descriptive matter and make identification of individual items easier the liberty has been taken of using the catalogue of the Arthur H. Thomas Co. of Philadelphia as a general guide. The numbers assigned to the different articles are for the most part in accordance with that catalogue. The same or equivalent articles can be secured from many other dealers in apparatus and chemicals. Prices have been omitted on account of the difficulty of obtaining accurate current information. The entire list will closely approximate a cost of $1 600.

APPARATUS FOR WATER-WORKS LABORATORIES.
(Listed according to the catalogue of Arthur H. Thomas Co.)

Catalogue Number.	Quantity.	Article.
1 008	2	Adapters, curved light wall, 150 x 18 mm.
1 160	2	Aprons, laboratory, rubber cloth, 25 x 36 in.
1 188		Asbestos Board, 42 x 48 in.
	1 sheet	9/16 in. thick.
	1 sheet	½ in. thick.
1 197		Asbestos Mats, metal bound edge, ½ in. thick.
	1	8½ x 8½.
	1	11 x 11.
1 199	½ lb.	Asbestos Paper, white fiber, 36 in. wide.
1 472	1	Incubator, C.S. & E., No. 31. 110 volts, 30 in. x 20 in. x 18 in.
1 540	1	Incubator, Hearson Model "C." 12 in. x 12 in. x 14 in. Gas.
1 598	1	Hot Air Sterilizer, U. S. Army model. 18 in x 24 in. x 14 in. for gas.
1 680	1	Autoclave, S.D. Horizontal, 24 in. x 21 in. Gas.
1 842	1	Balance, Analytical, Troemner, No. 50.
1 918	1	Balance, Harvard Trip, 6 in. plates.
1 974	1	Set Balance Weights, 1 mg. to 50 g., lacquered gram pieces.
2 054	1	Set Balance Weights of brass, 1 000 grams.
2 110		Beakers, Pyrex, Griffin low form, spout.
	10	100 cc.
	12	250 cc.
	12	400 cc.
	6	600 cc.
	3	1 000 cc.
2 128	12	Beakers, Pyrex, Berzelius form without spout, 300 cc.
2 171	1	Blower, Foot Power, on legs, 9 in. diameter.
2 200		Bottles, narrow mouth, flint glass.
	12	4 oz.
	12	16 oz.
2 204		Bottles, wide mouth, flint glass.
	6	4 oz.
	6	16 oz.
2 220		Bottles, laboratory, narrow mouth, flat stopper.
	12	250 cc.
	12	500 cc.
	12	1 000 cc.
2 221	3 doz.	Bottles, ditto, wide mouth, 4 oz.
2 222		Bottles, narrow mouth, flint glass, mushroom stopper.
	6	8 oz.
	6	16 oz.
	1 doz.	1 qt.
	1 doz.	2 qt.
	6	1 gal.
2 244	1	Balsam bottle, 45 cc.
2 256	3	Dropping bottles, glass stopper, 1 oz.
2 257	6	Bottles, dropping, flint glass, flat stopper, 100 cc.
2 270	6	Bottles, oil sample, flint glass, 4 oz.
2 312		Reagent Bottles, narrow mouth, with ground glass labels.
	1	No. 131, Acetic acid.
	1	No. 126, Alcohol.
	1	No. 108, Amm. Hydroxide.
	1	No. 105, HCl. conc.
	1	No. 106, HCl. dil.
	1	No. 103, HNO_3, conc.
	1	No. 104, HNO_3, dil.
	1	No. 101, H_2SO_4, conc.
	1	No. 102, H_2SO_4, dil.
2 320	6	Specimen bottles, wide mouth, 3½ oz.
2 334	12	Bottles, water sample, 2 oz.
2 361	1	Brush, black bristle, tuft on end.
2 375	1	Brush, camel's hair, flat, 1 in. wide.
2 378	2	Brushes, camel's hair, in quill handle, 18 mm.
2 391	2 doz.	Brushes, Test Tube, tinned wire, tufted.
2 395	6	Brushes, tinned wire, ½ in. diam.
2 436		Burettes, Schellbach, straight stopcock.
	1	25 cc.
	4	50 cc.
2 480	2	Burettes, Squibb's Zero, complete outfit.
2 510	2	Burette Support, Chaddock, porcelain plate.

APPARATUS FOR WATER-WORKS LABORATORIES (*Continued*).

Catalogue Number.	Quantity.	Article.
2 520	2	Burette Support, with clamp.
2 540	2	Burner, Argand, with iron chimney.
2 552	1	Burner, Micro, ¾ in.
2 562	1	Burner, Bunsen, with 3 tubes.
2 582	4	Burner, Tirrill.
2 592	1	Burner, Scimatco patent, 25 mm.
2 623	1	Wing top for Tirrill burner.
2 862		Casseroles, Coors Porcelain.
	3	150 cc.
	1	375 cc.
	3	500 cc.
	3	750 cc.
3 200	2	Clamps, Bunsen, length 9 in.
3 214	2	Clamp Holders, for ½-in. rods.
3 246	1	Clamp, Stoddart, 4½-in.
3 269	5	Clamps, Hoffmann, for ⅜-in. tube.
3 280		Clamps, Mohr's pinchcock.
	3	2½ in.
	3	3½ in.
3 661	2 sets of 12	Color comparison tubes, Nessler, low form, 100 cc. Height of mark uniform at about 150 mm.
3 664	4 sets of 12	Color tubes, Nessler, A.P.H.A., 50 cc. Mark uniform at about 210 mm.
	4 sets of 12	Ditto 100 cc. Mark uniform at about 325 mm.
3 797	1	Hydrogen-ion set, La Motte, complete, color tubes for range pH 5.6 to 7.4.
3 901	1	Condenser, Liebig, with rubber connections, 400 mm. shoulder to shoulder.
3 940	1	Condenser Support.
4 040	1	Cone, Imhoff, for sludge, 1 liter.
4 050		Corks, XXX quality.
	20	No. 1, 5/16 in., bottom diameter.
	20	No. 2, ¾ in., bottom diameter.
	25	No. 3, 13/32 in., bottom diameter.
	50	No. 4, 7/16 in., bottom diameter.
	50	No. 5, ½ in., bottom diameter.
	50	No. 6, 9/16 in., bottom diameter.
	50	No. 7, ⅝ in., bottom diameter.
	50	No. 8, 21/32 in., bottom diameter.
	50	No. 10, 13/16 in., bottom diameter.
	25	No. 12, 15/16 in., bottom diameter.
	20	No. 14, 1 in., bottom diameter.
	20	No. 16, 1 1/8 in., bottom diameter.
4 054		Corks, XXX quality, short taper.
	10	No. 17, 1 9/32 in., bottom diameter.
	10	No. 19, 1⅜ in., bottom diameter.
	10	No. 22, 1 9/16 in., bottom diameter.
	10	No. 26, 1 15/16 in., bottom diameter.
4 064	1	Cork borers, hard brass, 9 in set, 3/16 in. to 9/16 in.
4 078	1	Cork screw.
4 088	1	Counter, Hand (Tally Register), Veeder.
4 096	1	Counting Apparatus, Jeffer.
4 122		Crucibles, Coors, Porcelain, without covers, High form.
	3	Size No. 0.
	3	Size No. 1.
4 125		Covers, only, for No. 4 122 crucibles.
	3	To fit Crucible No. 0.
	3	To fit Crucible No. 1.
4 128		Crucibles, Coors Porcelain, low form, without covers.
	3	Size No. 1.
4 131		Covers, only, for No. 4 128 crucibles.
	3	To fit Size No. 1.
4 135		Crucibles, Gooch, Coors porcelain.
	3	Size No. 3.
4 158	1	Crucible, Opaque Silica, Glazed, high form Cap. 30 cc.
4 159	1	Cover for above.
4 332		Culture dishes, Petri, bottom glass only.
	9 dos.	Outside diameter, 95 mm.; depth, 15 mm.
4 335	100	Culture Dish Covers, of porous red earthenware. Inside diameter 97 mm.

APPARATUS FOR WATER-WORKS LABORATORIES (*Continued*).

Catalogue Number.	Quantity.	Article.
9 446		Culture tubes, heavy wall, without lip.
	200	75 mm. x 10 mm.
	300	120 mm. x 18 mm.
	200	150 mm. x 20 mm.
	200	180 mm. x 22 mm.
4 408		Cylinders, graduated, with spout.
	2	10 cc.
	3	100 cc.
	1	250 cc.
	2	500 cc.
	2	1 000 cc.
4 436	2	Desiccators, Scheibler. Inside diameter, 150 mm.
4 454	1	Desiccator Plate, glazed porcelain, diameter 140 mm.
4 480		Dishes, Coors Porcelain, spout.
	6	Size No. 0.
	6	Size No. 3.
	6	Size No. 6.
	1	Size No. 8.
4 494	3	Dishes, opaque silica, spout and round bottom. 100 cc. size, 3¼ in. diameter.
4 512	1	Dish, preparation, Stender, diameter 50 mm.
4 513	1	Dish, preparation, Stender, height 90 mm.
4 564	2	Forceps, med. fine, straight points, 100 mm. long.
4 565	2	Forceps, med. fine, curved points, 110 mm. long.
4 680	1	Distilling Apparatus, Barnstead, for gas heat. Capacity per hour, 1 gal.
5 081	3	Files, round, bastard cut; length of cut portion, 6 inches.
5 083	3	Files, triangular, 6 inches.
5 170		Filter paper, Munktell, No. 0.
	1 box	Diameter 125 mm.
	1 box	Diameter 185 mm.
5 202		Filter paper, Whatman, No. 2.
	3 boxes	Diameter 150 mm.
	3 boxes	Diameter 185 mm.
	3 boxes	Diameter 240 mm.
5 214		Filter paper, Whatman, No. 44.
	1 box	Diameter 90 mm.
	1 box	Diameter 125 mm.
5 288	1	Filter pump coupling, faucet thread, ⅜ in. size.
5 296	1	Filter pump, or aspirator, Richards, 7 in. x ¾ in. size.
5 314	3	Filter tubes, 37 mm.
5 324		Flasks, Pyrex, flat bottom, vial mouth.
	6	300 cc.
	6	500 cc.
	6	1 000 cc.
5 328	3	Flasks, Pyrex, flat bottom, heavy ring neck, 500 cc.
5 342		Flasks, Erlenmeyer, Pyrex, vial mouth.
	6	100 cc.
	6	300 cc.
	6	500 cc.
	3	1 000 cc.
4 955	3	Flasks, extraction, Pyrex, flat bottom, wide neck, vial mouth, 100 cc.
5 430		Flasks, filtering, side tubulation.
	2	500 cc.
	1	1 000 cc.
5 442	6	Flasks, Kjeldahl, Pyrex, round bottom, 650 cc.
5 460		Flasks, volumetric, without stoppers.
	3	50 cc.
	6	100 cc.
	2	200 cc.
	3	250 cc.
	2	500 cc.
	2	1 000 cc.
5 461		Flasks, volumetric, ground glass stoppers.
	1	50 cc.
	2	100 cc.
	1	200 cc.
	1	250 cc.
	2	500 cc.

APPARATUS FOR WATER-WORKS LABORATORIES (*Continued*).

Catalogue Number.	Quantity.	Article.
	1	1 000 cc.
5 548	1	Forceps, brass, straight.
5 551	1	Forceps, steel, 125 mm.
5 562	2	Forceps, Stewart, cover glass.
5 570		Funnels, glass, 60°.
	6	Diameter 1½ in.
	6	Diameter 3 in.
	6	Diameter 4 in.
	6	Diameter 6 in.
5 572		Funnels, glass, 60°, long stems.
	1	Diameter 2 in.
	2	Diameter 3 in.
	2	Diameter 4 in.
	2	Diameter 5 in.
5 584	2	Funnels, ribbed, diameter 10½ in.
5 587	2	Funnels, enamel ware, 6 in.
5 664	2	Funnel Support, wood, four funnels.
5 666	1	Funnel Support, 6 holes.
5 722	1	Furnace, Hoskins, Type FD 103.
5 724	1	Rheostat for same, 110 volts.
6 000	1	Gas Generator, Kipp, 500 cc.
6 080		Glass tubing, bending.
	25 ft.	5 mm.
	25 ft.	7 mm.
	25 ft.	9 mm.
	25 ft.	12 mm.
6 090		Glass Rod, bending.
	20 ft.	5 mm.
	20 ft.	7 mm.
6 183	1	Hydrometer, Spec. Gravity 1.000 to 1.200.
6 284	1 doz.	Jars, Screw Cap., 16 oz. capacity.
6 300		Labels, Dennison, gummed.
	2 boxes	No. 219.
	1 box	No. 223.
6 302	1 box	Labels, No. 2 004.
6 308	1 box	Labels, Micro Slide.
6 324	1 pkg.	Lens Paper, Japanese, 7½ in. x 11 in.
6 350	1	Magnifier, Engraver's Glass, No. 146, 3.5 X.
6 375	1	Meter Stick, millimeters and inches.
6 604	1	FF8 Microscope, Fine Lever Adjustment, Bausch and Lomb Oil Immersion, with Abbe Condenser.
6 836	1	Ocular Micrometer Disc, 21.3 mm. diameter.
6 842	1	Ocular Micrometer Disc, Whipple.
7 020	1 oz	Micro cover glasses, square; size 18 mm. No. 2.
7 034	½ gross	Micro slides. Standard White, Blue Label.
7 040	6	Micro Culture Slides, 3 in x 1 in.
7 304		Mortars, Porcelain, rough inside.
	1	65 mm.
	1	110 mm.
7 318	1	Mortar, iron, with pestle; 1 quart.
7 410	1	Needle, inoculating, 1½ in. No. 26 platinum wire.
7 413	1	Needle, inoculating, 3½ in. No. 24 chromel wire.
7 442	1	Distilling Apparatus with Gilmer Electric Heaters for 110 volts. Six burners. To stand on table.
7 461	1	A substitute for 7 442. Hangs on wall.
7 503	6	Kjeldahl Connecting Bulls, spherical, with straight connecting tube. Pyrex.
7 780	1	Oven, A. & S. Electric without regulator 3½ x 11½ x 8½ in. 110 volt.
7 964	10	Pencils, wax, blue.
8 150		Pipettes, transfer.
	6	5 cc.
	6	10 cc.
	3	20 cc.
	3	25 cc.
	3	50 cc.
	1	100 cc.
8 160		Pipettes, Mohr's measuring.
	2	1 cc. in $^1/_{10}$ divisions.
	2	1 cc. in $^1/_{100}$ divisions.
	3	5 cc. in $^1/_{10}$ divisions.

APPARATUS FOR WATER-WORKS LABORATORIES (*Continued*).

Catalogue Number.	Quantity.	Article.
	6	10 cc. in 1/10 divisions.
8 180	75	Pipettes, bacteriological, for water, 1 cc.
8 184	36	Pipettes, U. S. Public Health Service, for water, 11 cc.
8 223	3	Pipettes, dropping, 4 in., curved tip.
8 322	1	Pliers, steel, flat nose, side cutting.
8 758	1	Ring, Suberite, 5½ in. outside diameter.
8 761		Rings, Support, iron, 4½-in. radius.
	2	2½-in. diameter.
	2	3½-in. diameter.
	2	4½-in. diameter.
	2	5½-in. diameter.
8 764		Rings, Support, straight.
	1	2½-in. diameter.
	1	3½-in. diameter.
	1	4½-in. diameter.
	1	5½-in. diameter.
8 810		Rubber Stoppers, Solid.
	¼ lb.	No. 00.
	¼ lb.	No. 0.
	1 lb.	No. 1.
	¼ lb.	No. 3.
	1 lb.	No. 4.
	¼ lb.	No. 5.
	1 lb.	No. 6.
	4 lb.	No. 7.
	2 lb.	No. 8.
8 811		Rubber Stoppers, one hole.
	¼ lb.	No. 3.
	¼ lb.	No. 4.
	¼ lb.	No. 5.
	1 lb.	No. 6.
	1 lb.	No. 7.
	1 lb.	No. 8.
8 812		Rubber Stoppers, two hole.
	¼ lb.	No. 3.
	¼ lb.	No. 4.
	¼ lb.	No. 5.
	¼ lb.	No. 6.
	1 lb.	No. 7.
	1 lb.	No. 8.
8 830		Rubber Tubing, laboratory, thick wall.
	6 ft.	¼-in. bore.
	6 ft.	3/16-in bore.
	20 ft.	¼-in. bore.
	10 ft.	⅜-in. bore.
	6 ft.	½-in. bore.
8 840		Rubber Tubing, A.C., Pure Gum, thick wall.
	10 ft.	5 mm.-bore.
	5 ft.	8 mm.-bore.
8 844		Rubber Tubing, Pressure.
	5 ft.	¼-in. bore.
	3 ft.	½-in. bore.
	3 ft.	¾-in bore.
8 846	3 ft.	Rubber Tubing, for Gooch crucibles; inside diameter (cylindrical) 1¼ in; outside diameter (flat), 1½ in.
8 930	1	Shears, 10 inch.
8 994	2	Spatulas, Horn, double, 120 mm.
8 998	1	Spatula, steel, 7-in. blade.
9 000	2	Spatula, stainless steel, 4-in. blade.
9 194	1	Staining Dish, glass, 75 mm. x 58 mm.
9 287	3	Stopcocks, glass. Bore of stopcock plug, 2 mm.
9 503	3	Test Tube Supports, single deck, double row, 12 holes.
	1	Test Tube Supports, 24 holes.
9 525		Thermometers, Class G.
	3	Centigrade, −10° to 100°.
	1	Centigrade, 0° to 360°.
	1	Centigrade, 0° to 250°.
9 526	2	Thermometers, Fahrenheit, 0° to 220°.
9 607	1	Thermometer, Pocket, Fahrenheit, −30° to 120°.
9 694	1	Tongs, crucible, 9 in.

APPARATUS FOR WATER-WORKS LABORATORIES (*Continued*).

Catalogue Number.	Quantity.	Article.
9 720	3	Triangles, iron wire, pipe stem; length of side, 2½ in.
9 721	3	Triangles, iron wire, pipe stem, flange in centre; length of side, 2½ in.
9 730	2	Tripods, cast-iron, 6 in. x 3 in.
9 731	3	Tripods, cast-iron, 9 in. x 4 in.
9 804	1 gross	Vials, Shell Vials, 40 x 10 mm.
9 836		Watch Glasses.
	6	75 mm.
	6	100 mm.
	3	150 mm.
9 840	1 pair	Watch Glasses, counterpoised in pairs, 75 mm.
9 868	2	Water Bath, cast-iron, 5½ in.
9 896	1	Water Bath, of copper, tin lined, 23 in. x 13½ in x 5 in., seven openings.
9 941	3	Sedgwick-Rafter Funnel, ungraduated, with attachment and rubber stopper.
	10 lbs.	Berkshire Sand.
9 943	1	Counting Cell.
9 944	6	Cover Slips.
9 964		Weighing Bottles, flat bottom, wide form, ground glass stopper.
	2	80 x 45 mm.
	2	50 x 30 mm.
9 983	4 spools	Copper Wire, B. & S. Gage 18.
9 994	10 squares	Wire Gauze, 5 in., 20 mesh.

ADDITIONAL BACTERIOLOGICAL APPARATUS.
(Listed according to catalogue of Peter Gray & Sons, Cambridge, Mass.)

Catalogue Number.	Quantity.	Article.
7	3	Pipette Boxes for sterilizing 2 in. x 2 in. x 12 in.
7	3	Pipette Boxes for sterilizing 2 in. x 2 in. x 16 in.
4	1	Agar Melting Bath.
..	12	Wire Baskets for culture tubes 4 in. x 4 in. x 5 in.
		EQUIPMENT OBTAINABLE FROM LOCAL DEALERS.
..	1	Refrigerator.
..	1	Gas hot plate with two burners.
..	1	Electric hot plate 6 in. to 10 in. diameter.
..	2	Double boilers, enamel ware, 2 qt.
..	4	Stone jars for waste, no covers, 4 gal.

NOTE: The items of a sieve shaker and testing sieves for sand analysis have not been included. They are often a part of engineering or plant equipment outside the laboratory. If they are desired, an additional cost of $200 to $300 will be entailed, according to the type of shaker selected. In this connection attention is called to the equipment manufactured by the W. S. Tyler Co. of Cleveland, description of which is given in their catalogue.

Other items that may be found useful for some laboratories are a motor-driven stirring apparatus, such as Arthur H. Thomas Number 4 780 and a Jackson turbidimeter, Number 9 770.

Chemicals for Water-Works Laboratories.

This list is made up from the catalogue of the Arthur H. Thomas Co. For the most part Baker's Analyzed Chemicals have been specified in order to preserve uniformity. There are other reliable brands that may be obtained and used with equal satisfaction.

Amount.	Chemical.
1–1 lb.	Acetic acid, c.p. Baker anal. 99.5 per cent. Glacial.
2–4 oz.	Carbolic acid, c.p. Baker, loose crystals.
1–6 lbs.	Hydrochloric acid, c.p. Baker anal.
1–6 lbs.	Hydrochloric acid, com.
1–1 lb.	Nitric acid, c.p. Baker anal.
1–1 oz.	Sulphanilic acid, purified, Baker and Adamson.
1–9 lbs.	Sulphuric acid, c.p. Baker anal.
1–9 lbs.	Sulphuric acid, com. conc.
1–1 gal.	Ethyl alcohol, denatured.
1–1 oz.	Alphanaphthylamine, Baker anal.
4 oz.	Aluminum sulphate, c.p., crystals, Baker anal.
4 oz.	Ammon. aluminum sulphate c.p. Baker anal.
8 oz.	Ammonium carbonate, c.p. Baker anal.
2 oz.	Ammonium chloride, c.p. Baker anal.
4 lbs.	Ammonium hydroxide, c.p. Baker anal.
1 oz.	Ammonium oxalate, c.p. Baker anal.
2 oz.	Asbestos, medium fibre, washed in acid, for Gooch crucibles.
2 oz.	Barium chloride, c.p. Baker anal.
1 lb.	Calcium carbonate, lump, marble.
2 oz.	Calcium carbonate, c.p. Baker anal.
½ lb.	Calcium oxide, U.S.P. M.W.L.
2 lbs.	Chloroform, c.p. Baker anal.
4 oz.	Copper sulphate, c.p. cryst., Baker anal.
3 lbs.	Cotton, absorbent.
2 oz.	Iron ammonium sulphate, c.p., fine crystals (ferrous), Baker special.
2 oz.	Magnesium sulphate, c.p. Baker anal.
4 oz.	Mercury bichloride, c.p. Baker anal.
1 oz.	Methyl Orange Indicator, Baker anal.
1 oz.	Phenolphthalein Indicator, Merck's Blue Label.
2 g.	Platinum, potassium chloride.
1 lb.	Potassium bichromate, crystals, tech. Merck's White Label.
1 oz.	Potassium bichromate, c.p. Baker anal.
2 lbs.	Potassium hydroxide, c.p. by alcohol, Baker anal.
2 oz.	Potassium iodide, c.p. Baker anal.
1 oz.	Potassium nitrate Baker anal. crystals.
2 oz.	Potassium permanganate, c.p. small crystals, Baker anal.
2 oz.	Potassium sulphocyanate, c.p. Baker anal.
1 oz.	Silver nitrate, c.p. cryst. Baker anal.
1 oz.	Silver nitrite, c.p. Baker and Adamson.
4 oz.	Sodium bicarbonate, c.p. Baker anal.
8 oz.	Sodium carbonate, c.p. anhydrous, Baker anal.
4 oz.	Sodium chloride, c.p. fused, Baker anal.
1 lb.	Sodium hydroxide, c.p. by alcohol, Baker anal.
4 oz.	Starch, soluble, Baker anal.
1 vial	Test Paper, litmus, blue, in vials of 100 strips.
1 vial	Test Paper, litmus, red, in vials of 100 strips.
1 pt.	Xylene, pure, acid free.
25 g.	Erythrosin, indicator, pure.
1 lb.	Calcium chloride, fused, for drying, purified, 70 per cent.
10 g.	Alizarin sodium monosulphonate, Coleman and Bell.
2 oz.	Cobalt chloride, c.p. Baker anal.
25 g.	Ortho Tolidin by alcohol.
2 oz.	Sodium phosphate, dibasic, anhydrous, Merck blue label.
2 oz.	Potass. phosphate, monobasic, anhydrous, Merck blue label.
10 g.	Methylene Blue for Bacilli, Coleman and Bell.
10 g.	Fuchsin, Basic, crystals, Coleman and Bell.
1/10 g.	Chlorphenol Red, Hynson, Westcott and Dunning.
1/10 g.	Brom Thymol Blue, Hynson, Westcott and Dunning.
500 cc.	Chlorphenol Red, Standardized Indicator Solution, .04 per cent. Hynson, Westcott and Dunning.

CHEMICALS FOR WATER-WORKS LABORATORIES (*Continued*).

Amount.	Chemical.
500 cc.	Brom Thynol Blue, Standardised Indicator Solution, .04 per cent., Hynson, Westcott and Dunning.
1 g.	Methyl Red, Hynson, Westcott and Dunning.
1/10 g.	Phenol Red, Hynson, Westcott and Dunning.
1 lb.	Agar, granular, "Bacto," Difco.
4 lbs.	Agar, 1½ per cent., nutrient, dehydrated, Difco.
4 oz.	Agar, dehydrated, Endo's, Difco.
2 oz. tube	Beef Extract, bacteriological, Difco.
8 oz.	Eosin-Methylene Blue Agar, dehydrated, Difco.
1 lb.	Gelatine, Bacto, Difco.
4 lbs.	Gelatine, Nutrient, dehydrated, Difco.
2 lbs.	Lactose Broth, dehydrated, Difco.
8 oz.	Peptone, Bacto, Difco.
4 oz.	Lactose, Bacto, Difco.

LIST OF BOOKS AND PERIODICALS SUGGESTED FOR USE OF WATER-WORKS LABORATORIES.

BOOKS.

PRESCOTT, S. C. AND WINSLOW, C.-E. A., 1924. Elements of Water Bacteriology. New York. John Wiley & Sons.

AMERICAN PUBLIC HEALTH ASSOCIATION. 1925. Standard Methods for the Examination of Water and Sewage. New York. American Public Health Association.

THRESH, JOHN C. AND BEALE, JOHN F. 1925. The Examination of Waters and Water Supplies, 3rd Edition. Philadelphia. P. Blakiston's Son & Co.

AMERICAN WATER WORKS ASSOCIATION. 1926. Manual of Water-Works Practice. Baltimore. The Williams & Wilkins Co.

STEIN, MILTON F. 1926. Water Purification Plants and their Operation, 3rd Edition. New York. John Wiley & Sons.

OLSEN, JOHN C. 1926. Chemical Annual. New York. D. Van Nostrand Co.

WHIPPLE, GEORGE C. 1927. The Microscopy of Drinking Water, 4th Edition. Revised by G. M. Fair and M. C. Whipple. New York. John Wiley & Sons.

FLYNN, A. D., WESTON, R. S. AND BOGERT, C. L. 1927. Water-Works Handbook, 3rd Edition. New York. McGraw-Hill Book Co.

SCOTT, WILFRED W. 1927. Standard Methods of Chemical Analysis, 4th Edition. New York. D. Van Nostrand Co.

POWELL, SHEPPARD T. 1927. Boiler Feed-Water Purification. New York. McGraw-Hill Book Co.

BUSWELL, ARTHUR M. 1928. The Chemistry of Water and Sewage Treatment. New York. The Chemical Catalog Co.

ELLMS, JOSEPH. 1928. Water Purification, 2nd Edition. New York. McGraw-Hill Book Co.

PERIODICALS.

Journals of the American Chemical Society.
Journal of the American Water Works Association.
Journal of the New England Water Works Association.
Public Health Reports. U. S. Public Health Service.
Water Works. Gillette Publishing Co., Chicago.

FRANCIS E. HALL.

Francis E. Hall died at his home in Worcester, Mass., on February 24, 1928, at the age of eighty-seven.

He was the second president of the New England Water Works Association and prior to his death the only living charter member.

He was water commissioner of Worcester from 1875 to 1883 and superintendent of the Quincy Water Company from 1884 to 1895.

In 1896, Mr. Hall became associated with the Union Water Meter Company of Worcester, Mass., which connection was continued until 1918, at which time he retired from active business life.

His long service in charge of the water supplies of Worcester and Quincy was marked by ability and fidelity to duty in full measure.

He was kindly in nature, cheerful under the most trying circumstances, and helpful to those with whom he came in contact.

Throughout his public service, business life, and years of retirement, it was always a pleasure to meet him and receive his kindly greetings.

He maintained his interest in the New England Water Works Association to the very end of his life and attended the meetings as long as his strength allowed him to.

His last days were spent quietly at his home in Worcester, and when he died full of years he left a fine record of usefulness and accomplishment.

The New England Water Works Association honored itself in electing Francis E. Hall as its president and will revere his memory.

GEO. W. BATCHELDER,
FRANK E. MERRILL.

BOOK REVIEW.

WATER PURIFICATION. By Joseph W. Ellms. Second Edition. New York and London. McGraw-Hill Book Co., Inc. Cloth; 6 x 9 in.; pp. 594; 161 illustrations. $7.00.

About ten years have elapsed since the publication of the first edition of this valuable book. During this time there have been notable developments in the science and art of water purification. The relation of the hydrogen-ion concentration of waters to the mechanism of purification processes has come to be appreciated. Super-chlorination followed by de-chlorination for the prevention of chlor-phenol and other noxious tastes has been applied on a large scale. The recarbonation of lime-softened waters has come into vogue. Double coagulation has been practiced with success, as has prechlorination. Sodium aluminate has come into use as a coagulant. We have battled over the question of iodizing water for the prevention of simple goiter and have learned more about the permissible loading of filter plants. Mechanical clarifiers have been developed for settling basins, and paddle mechanisms and the "hydraulic jump" have taken their place in mixing units. New underdrain systems have been tried in rapid sand filters, and sand-washing machines have been designed for slow sand filters.

All of these developments in water purification have been treated by Mr. Ellms in the second edition of his book. They make of it a thoroughly up-to-date work. The new matter adds over a hundred pages to the volume. Eighteen pages are found in a new chapter on "The Effect of the Hydrogen-ion Concentration of Natural Waters." The remaining new material is well scattered through the book.

The sequence of chapters remains practically the same as in the first edition. There are five introductory chapters dealing with the history of water purification, the classification of natural waters, the relation of water to health and the objects of water purification. Sedimentation and coagulation are treated in three chapters. There follow the chapters on filtration, of which there are eighteen. One of them considers filtration in general, four deal with slow sand filters, the remainder with rapid sand filters. In this section of the work are included chapters on the efficiency and cost of operating slow and rapid sand filters and on the capital cost of rapid sand filters. There are also two chapters each on the hydraulic devices used in rapid sand filters and on the equipment employed for handling chemicals. Power plant and pumping machinery in purification works, too, are treated. Of the remaining chapters two deal with the physical chemistry of water purification, two with disinfection, two with water softening and deferrization and one with the control of purification processes. The hydraulics of rapid sand filters and wash-water troughs are taken up in appendices which include also useful tabular material.

The merits of this revised edition of Ellms's "Water Purification" are unquestionable. It has but few shortcomings. A judicious deletion of some of the older material in a number of chapters, however, might well have been made. New material is sometimes added to old material where substitution would seem to have been indicated. This is true for example of Chapter IV where the newer statistics of water-borne diseases are poorly correlated with the older ones taken over from the first edition. As a result, the reader is apt to obtain from the old figures an erroneous impression of the situation. In connection with "water and disease" the revision might well have pointed out that more recent evidence does not bear out the "Mills-Reincke" theory. Furthermore, reference to the spread of respiratory infections by water seems unnecessarily alarming.

There are a number of omissions. Aëration, a very useful process of water purifica-

tion, is treated only incidentally in connection with deferrization. The "whirling mixer" as used at Albany, Providence and other recent plants is not mentioned. There is no reference to the newer designs of slow sand filters such as have been built at Hartford, Conn., and at Springfield and Lawrence, Mass. The fact that rapid sand filters are replacing "scrubbers" in the treatment of polluted waters preliminary to slow sand filtration is not noted.

It seems unfortunate that the "references" found at the end of chapters, though ample, are neither arranged chronologically nor alphabetically and thus lose much of their usefulness. The index is not complete, and the table of contents is a mere listing of chapters. This should not be so in a reference book.

As a teacher, the reviewer misses the inclusion in the book of more theoretical material. As editor of the JOURNAL of NEW ENGLAND WATER WORKS ASSOCIATION, he regrets to see reference made in certain cases to trade journals when the original paper appeared in the JOURNAL of the Association.

The first edition of Ellms's "Water Purification" was acclaimed the standard book on this subject; the second edition bids fair to insure its continuance as such.

GORDON M. FAIR.

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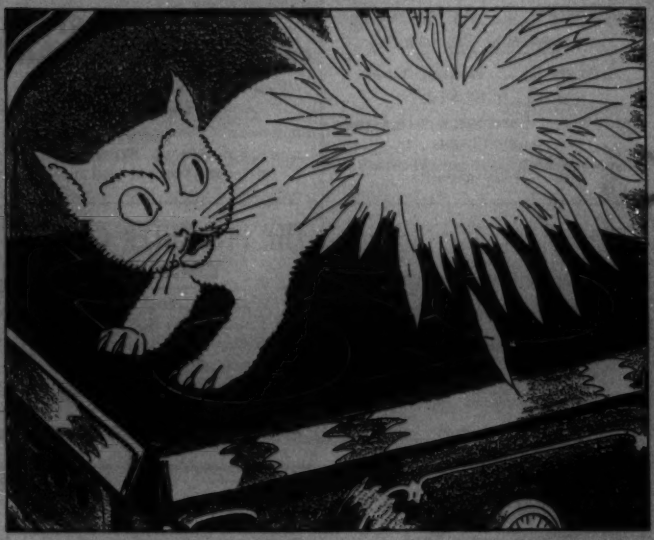

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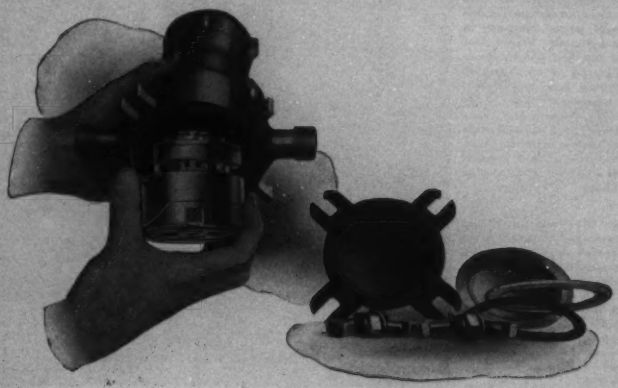

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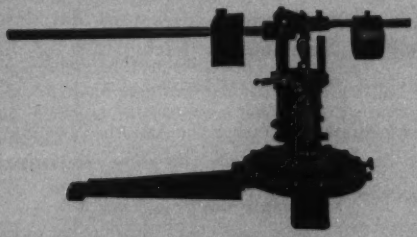

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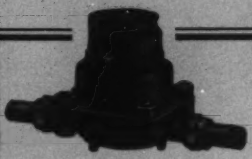

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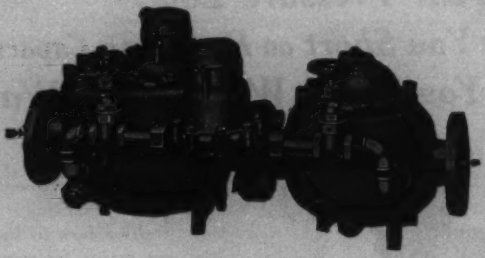

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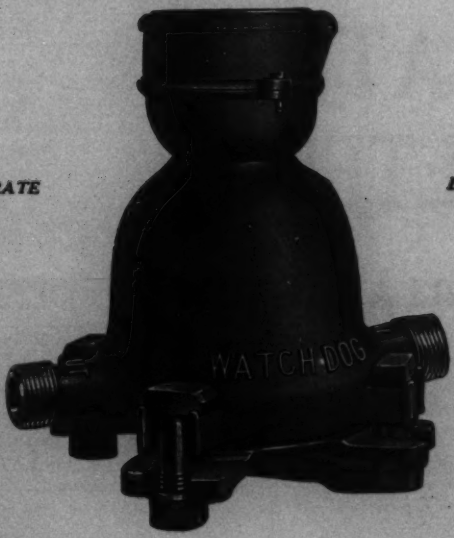

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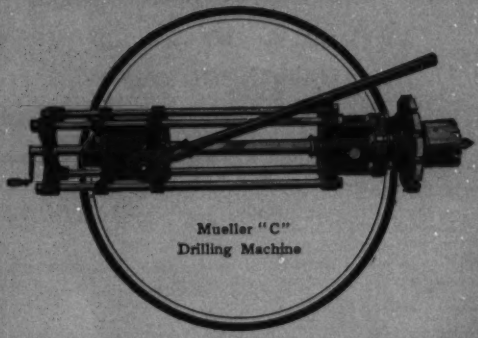

Mueller "C"
Drilling Machine

Heavy cuts are easy—

Mueller Yarning Iron G-10690. Made in two sizes with point thicknesses of ⅛" and ¼". It is of Octagon Steel and is approximately 10¼" long.

Mueller Pipe Joiner G-10728 is made of a special packing with a brass band riveted on the outside to which the clamp is securely riveted.

when this husky machine is used. Stripped of every pound of metal that can be spared without reducing its wearing qualities, the Mueller "C" Drilling Machine can be handled easily by two men without straining and one man can operate it if necessary.

All working parts are encased in dustproof housing and run in heavy grease. It gives clean-cut service on lateral or branch connections from 2" to 8" in pipe 4" to 48".

MUELLER CO. (*Established 1857*) **Decatur, Illinois**

Branches: New York, Dallas, San Francisco, Los Angeles
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ATTENTION
WATER WORKS
OF NEW ENGLAND

A few reasons why we solicit your inquiries on Water-Works Pumping Equipment:

First. — We make a specialty of furnishing Complete Water-Works Pumping Units of all types.

Second. — Total responsibility of installation is assumed by us.

Third. — We relieve the purchaser of every detail and turn the complete unit over to him under actual operation and with guarantee.

Fourth. — Every unit installed to date has exceeded its guarantee and has been completely accepted.

Remodeled Pumping Station at Bridgewater, Mass., completely installed by F. A. Mazzur Co., Inc. Barbour & Dixon, Eng'r's.

F. A. Mazzur Co., Inc.

141 MILK STREET, BOSTON

Another Notable Installation

THE ILLUSTRATION shows a 3,000,000 Gallon High Duty Pumping Engine we recently installed in the Arlington, Mass. High Level Pumping Station of the Metropolitan District Commission.

This pump was built by our principals, the Murray Iron Works Company of Burlington, Iowa, and installed in ample time to meet the heavy hot weather water demand this summer.

MURRAY IRON WORKS PUMPING ENGINE

This engine is of the cross compound opposed type with outside center packed water plungers. The steam cylinders are 16″ and 30″ diameter, pump plungers 10½″ diameter, all by 30″ stroke.

With 150 lbs. steam pressure (saturated) and 26″ vacuum, the pump delivers 2080 gallons per minute against 305 feet dynamic head and develops a duty of 138 million foot pounds per 1000 lbs. of dry steam, a remarkable performance for a unit of this relatively small size.

POWER AND PUMPING PLANTS;
ALSO AUXILIARY AND ALLIED EQUIPMENT

STARKWEATHER & BROADHURST, INC.

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Pumping Plant Contractors

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STEAM TURBINES
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ELECTRIC MOTORS
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Standpipes
Water Tanks
Gas Holders
and all other metal surfaces need the protection of
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Silica-Graphite
PAINT
BOOKLET NO. 67-B
JOSEPH DIXON CRUCIBLE CO. Jersey City, N. J.

WE announce our appointment as Sales Representatives of DAYTON-DOWD COMPANY, of Quincy, Ill., Manufacturers of Centrifugal Pumping Machinery. After exhaustive investigation, we present this line of equipment to the Trade in New England as being of the highest grade and thoroughly modern in design and manufacture.

We are prepared to furnish DAYTON-DOWD pumps in all sizes and for all classes of service, in steam, motor, gasoline and belt drive types, and solicit your inquiries, assuring you of our best efforts in your sales and service requirements, and of our appreciation of your continued confidence and patronage.

POWER EQUIPMENT CO.

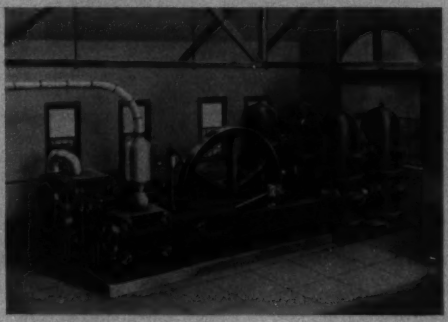
131 State Street, Boston, Mass.

MURRAY IRON WORKS CO.

(INCORPORATED 1870)

BURLINGTON, IOWA, U. S. A.

Builders of High Duty Pumping Engines



Murray High Duty Crank and Fly Wheel Pumping Engine, Opposed Type

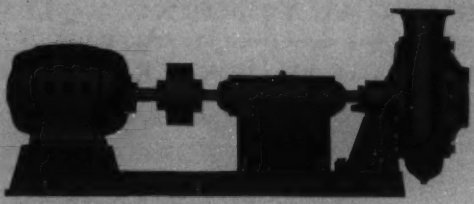
Engineers, Iron Founders, Boiler Makers

Corliss and Una-Flow Engines

Water-Tube, Fire-Tube and Internal-Furnace Boilers

Builders of Complete Power Plants

PLEASE SEND US YOUR SPECIFICATIONS AND CALLS FOR BIDS



Fairbanks-Morse Horizontal Trash Pump direct-connected to Fairbanks-Morse Ball-Bearing Motor

Now a great advance in sewage pumping

For the first time a pump has been designed that will handle fluids containing the fibrous and stringy matter found in sewage — without clogging, without preliminary screening, and without the excessive power consumption that characterizes the less satisfactory open impeller type of pump.

The secret of this pump's success lies in the design of the simple two-blade impeller. The blades of the impeller have well-rounded entering ends and are well filleted with the shrouds or sides. Thus a rag or other trash does not find sharp projections on which to catch and cause clogging. Since the impeller is the enclosed type, foreign matter, in passing through, does not come into contact with stationary side plates, but is promptly discharged through one of the large ports into the pump case. In this way power is conserved and efficiency increased.

This pump was designed by Mr. A. B. Wood who has been serving the city of New Orleans and other municipalities in the capacity of consulting engineer. It was originated by Mr. Wood to cope with the very unusual sewage problems found in New Orleans and met with immediate success.

Fairbanks-Morse Trash Pumps are made in two types, horizontal and vertical. They are ruggedly built to cope with severe service and at the same time they possess such refinements as ball bearings, smoothed fluid passages, and other marks of quality construction.

Ask for bulletins giving complete details.

FAIRBANKS, MORSE & CO., Chicago

28 branches in principal cities at your service.

FAIRBANKS-MORSE

PUMPS · DIESEL ENGINES · MOTORS

DE LAVAL

CENTRIFUGAL PUMPING EQUIPMENT

is the accepted standard for

MUNICIPAL WATER WORKS

WEYMOUTH, MASS.

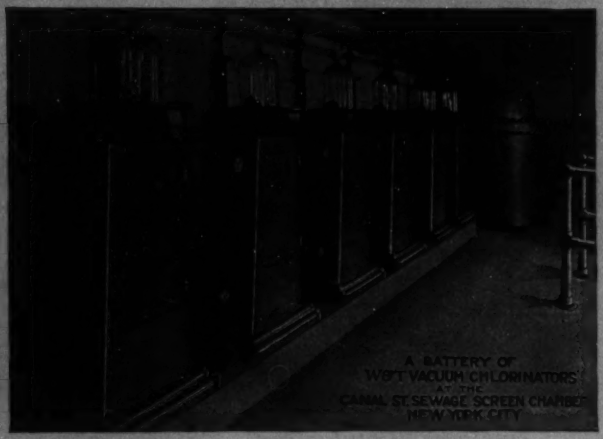
Recent DE LAVAL installation of 2½ million gallons per day gasoline engine driven pumping unit.

Pump normally delivers 1800 gallons per minute against 120 feet head and for fire purposes will deliver 1000 gallons per minute against 160 feet head.

Contract included the furnishing, installating and starting of the complete equipment. We assume full responsibility for the entire installation until delivered to the owner.

Ask for De Laval Publication.

TURBINE EQUIPMENT CO. of NEW ENGLAND
CHAMBER OF COMMERCE BUILDING
80 Federal St., Boston
NEW ENGLAND REPRESENTATIVE FOR
DE LAVAL STEAM TURBINE COMPANY
Trenton, N. J.



The W & T Vacuum Chlorinator

LONG LIFE
The first vacuum chlorinator is still in operation.

ACCURATE
Indicates the true chlorine flow —average error negligible.

SIMPLE
No diaphragm valves on the chlorine supply.

LEAK PROOF
Any leaks would be *into* the apparatus — because of the vacuum.

NON-CORRODIBLE
Silver — platinum — glass — hard rubber — nothing else comes in contact with wet chlorine.

VISIBLE CONTROL
The glass bell jar lets you see what is going on.

LOW UP-KEEP
Averages less than 1% per year.

EFFICIENT
The vacuum completely empties the chlorine cylinders.

Write for Techinical Publication No. 38N

"The only safe water is a sterilized water"

WALLACE & TIERNAN
COMPANY, INCORPORATED
NEWARK : NEW JERSEY

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PITTSBURGH DALLAS KANSAS CITY SEATTLE ST. LOUIS BUFFALO
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8a3

MERRIMAC CHEMICAL COMPANY AND ITS CUSTOMERS

Our Technical Service Department is useful in two ways:

1. Through scientific knowledge, strengthened by experience, it is able to give our customers helpful advice.

2. By its contact with customers it enables us to make our products conform closely to the customers' needs.

PLEASE CALL UPON OUR TECHNICAL SERVICE DEPARTMENT TO DISCUSS *YOUR* PROBLEMS

CMC

MERRIMAC CHEMICAL COMPANY

BOSTON

PRECALKED JOINT PIPE

Can be laid three times as fast as ordinary pipe, for half the labor. B. & S. type. Sand cast. Precalked Fittings also.

McWane Cast Iron Pipe Company

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Sales Representatives:
FRED A. HOUDLETTE & SON
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BIRMINGHAM, ALA.

Main's Hotcoating for the inside of standpipes and water tanks, will stop all pitting and corroding, and is guaranteed for seven years.

Also

Main's Coverall Salt Air Paint, for the outside of standpipes and water tanks, guaranteed for four years.

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GRIP PIPE FITTINGS

Connect without threading

As an Emergency Pipe Clamp

Before

After

Makes Possible an Immediate Repair. Saves Both Time and Money

MANUFACTURED BY

WARE COUPLING & NIPPLE CO.

WARE, MASS., U. S. A.

40 Years Old—Still Serving!

In the life of a pipe line, forty years is a long time — particularly if it is spent underground, subject within and without to corrosive onslaughts.

The pipe that can stand it is the pipe for service lines. That genuine wrought iron pipe has the necessary endurance is clearly demonstrated by service records all over the country of which the above photograph is an interesting example.

Here is a two-foot section from a line laid in 1886 by the Atchison Water Co. It is still good. It was removed simply to admit a valve. The line as a whole is in its 41st year of constant, uninterrupted service.

For sixty years, Byers has made pipe from genuine wrought iron. Its quality today is no less than that which has already defied rust for two, even three generations. Such, surely, is the ideal pipe for service lines.

A. M. BYERS COMPANY

Established 1864 Pittsburgh, Pa.

BYERS PIPE

GENUINE WROUGHT IRON

W. B. Hubbard & Sons Co.

FRANK W. HUBBARD, President-Treasurer
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WATER WORKS SUPPLIES

176 Oliver Street, Boston, Mass.

PIERCE-PERRY CO.

SUCCESSORS TO
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JOBBERS OF
Heating and Plumbing Supplies
Steel, Wrought Iron and Brass Pipe
Water Works Materials

DISTRIBUTORS OF
Huffman Valves and Controlled Heat Equipment

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BOSTON PIPE & FITTINGS CO.

WHOLESALE JOBBERS

Byers Genuine Wrought Iron Pipe

National Pipe

COMPLETE LINE OF WATER WORKS SUPPLIES

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NOTICE:

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Your card may be inserted here at a rate of $12 per year.

We Carry in BOSTON STOCK for Immediate Shipment

CAST IRON BELL AND SPIGOT WATER PIPE AND FITTINGS
FLANGED PIPE in full and short lengths
WROUGHT PIPE

FRED A. HOUDLETTE & SON
(Incorporated)

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Quotations furnished promptly for shipment from Foundry

CEMENT LINED SERVICE PIPE

With Specially Adapted Lead-lined Fittings

Also Curb Cocks which eliminate Iron to Brass Corrosion both inside and out.

CEMENT LINED PIPE CO.
LYNN, MASS.

SUMNER & DUNBAR

Manufacturers of and Dealers in
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Byers' Wrought Iron Pipe
Service and Valve Boxes
Cast Iron Pipe and Fittings

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Telephone, Liberty 1350

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(Reg. U.S. Pat. Off.)

FIRE HYDRANTS

For Standard and High Pressure Service

Mathews Hydrants are simple in construction; hence durable, easily repaired, and maintained at low cost.

A real Frost Case makes Mathews Hydrants completely frost proof, and with an easily installed

Extension Section

makes the Mathews readily adaptable to new grades and conditions.

Water Works Gate Valves
Valve Boxes — Indicator Posts

CAST IRON PIPE FITTINGS

"Sand-Spun" centrifugally cast pipe
Cast in refractory molds
No chill—Standard bell and beaded spigot

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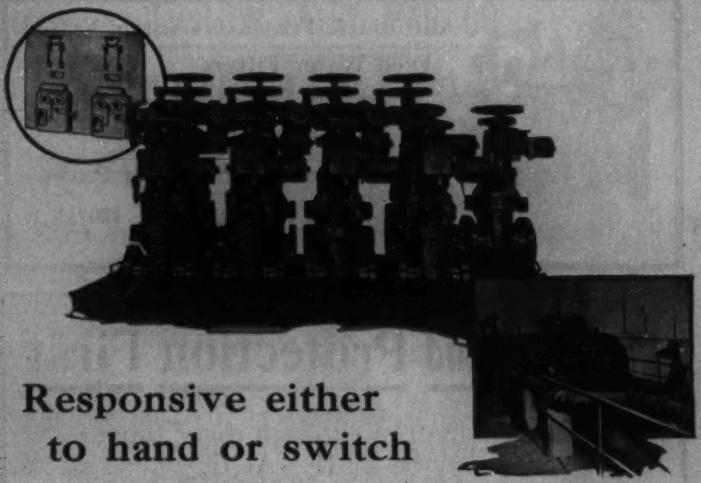
PHILADELPHIA, PA.



Responsive either to hand or switch

THROUGH one or more control stations located within easy reach, Kennedy Electrically Operated Gate Valves, installed, of necessity perhaps, in inaccessible places throughout your plant, can be opened or closed safely, conveniently, and much more quickly than by hand operation.

This is most desirable under any condition, and a necessity in an emergency. They can be operated by hand without interfering with the motor connections or the limit setting.

Kennedy electrically operated valves have a wide application in water works and power plant service. They can be arranged for control from one or a number of distant points, from positions above or below the valves, with control on pedestal or panel, and for alternating or direct current.

The motor is fully enclosed and waterproof, with an automatic lubricating system, and the operation is positive and troubleproof. Kennedy Valves now in service can be provided with this type of control.

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KENNEDY

VALVES~PIPE FITTINGS~FIRE HYDRANTS

Automatic Pressure Control Valves
Feed Water Filters
Portable Fire Hydrant Heads
Hydraulic Engines
Hydraulic Booster Pumps

ROSS VALVE MFG. CO., INC. TROY, N. Y.
ESTABLISHED 1879

Health and Protection First

Water delivered through dirty pipes may be a MENACE.

Incrusted water pipes mean inefficiency and loss of Fire Protection.

We Guarantee the Results of Our Method of Cleaning.

WRITE US.

National Water Main Cleaning Co.

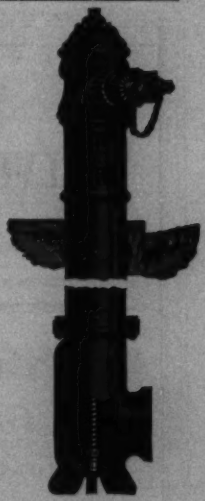
50 Church Street New York City

A Classified Directory
of Advertisements is arranged for your convenience in the back of this Journal.

LUDLOW VALVE MFG. CO.

MANUFACTURERS OF

VALVES and FIRE HYDRANTS



This hydrant is anti-freezing, because when the drainage is good no water is left in it to freeze.

The drip is directly in the bottom of the hydrant and drains perfectly. It is protected by its valve, which never leaves its socket and cannot be clogged.

DOUBLE AND SINGLE GATE VALVES,

ALSO CHECK VALVES,

FOOT VALVES.

FIRE HYDRANTS.

YARD, WASH, AND FLUSH HYDRANTS.

☞ SEND FOR CIRCULARS ☜

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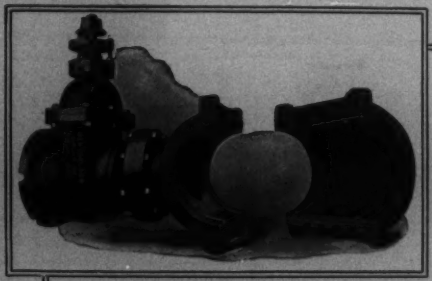

Rensselaer Tapping Sleeves

were brought out to meet a growing demand for a "BETTER" Tapping Sleeve. They were designed to suit conditions met in actual practice.

They can be used with all standard makes of Tapping Machines.

POINTS OF
SUPERIORITY

Have two lead rings.

Require less lead for calking.

Iron washers not required.

Bolting flanges are made full length of sleeve, giving great strength.

Have greater thickness of hubs on ends.

Easier to center on pipe before pouring lead.

Cost less to install.

Book No. 11 gives full information.

Ask for prices.

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New England Sales Manager, Lock Box 2, Northboro, Mass.

RENSSELAER VALVE COMPANY, TROY, N.Y.

THE CHAPMAN VALVE MANUFACTURING COMPANY

Manufacturers of

Gate Valves Drip Valves

Gate Fire Hydrants

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Type of Eddy Hydrant Popularly Used

More Than Sixty Years of Experience Goes Into All

EDDY

Hydrants and Valves

BUILT TO MEET EVERY EXACTING REQUIREMENT OF WATER-WORKS SERVICE

Practical water-works men instantly recognize the superior features of Eddy products. For instance, with the hydrant.

A damaged valve can be replaced in a few minutes — Water hammer is avoided by the valve closing against the pressure and the use of the cut-off under the valve, which gradually closes it —
Stems cannot be bent in closing the hydrant.
Nothing can lodge on the valve seat to prevent closing of the valve —
The Drip Rod can be removed without interfering with the hydrant in any manner —
The position of the stem of the hydrant indicates accurately the position of the valve —
Whatever can pass the valve opening will pass the standpipe —
No frost case necessary —
All of these points are explained thoroughly in our catalogue, which will pay you to study.

The Eddy Valve, Too

Has its distinctive and individual features. The double disk gates are free to adjust themselves in different positions every time the valve is closed, thereby keeping smooth and tight faces. And two bronze hooks on the ball loosely engage with the gates to prevent them from spreading at the top. The center bearing gates are forced to their seats with equal pressure at all points. There is a good deal more worth knowing about Eddy Valves. Further details will be sent for the asking.

Other Eddy Products

The Eddy line of water-works products also includes horizontal and vertical check valves, foot valves, hydraulically operated valves, indicator posts, etc.
All goods made by the Eddy Valve Company are manufactured exclusively at Waterford, New York.

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WATERFORD, N. Y., U. S. A.

EMAUS PIPE FOUNDRY,
DONALDSON IRON CO.,

MANUFACTURERS
...OF...

CAST IRON PIPE

...AND...

Special Castings for Water and Gas.
Also Flange Pipe, Street Castings,
Manhole Heads and Covers, etc.

EMAUS,
LEHIGH COUNTY, PA.

J. G. EBERLEIN, President and Treasurer.
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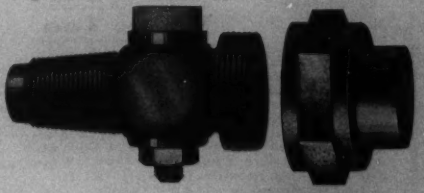
The "BEST" Cast Iron Curb Box

Top section is interchangeable with the "Slide Type" Buffalo Box

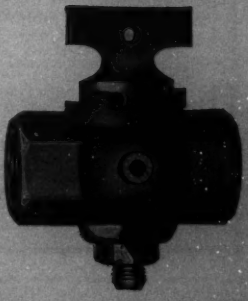
No change necessary in wrench or shut off keys



"CALDWELL" Water Works
Brass Goods, Curb and
Valve Boxes

None better and few as good

GEORGE A. CALDWELL CO.
Mattapan Square
BOSTON, MASS.



Reducing FIRST costs as well as *last* costs with CAST IRON PIPE

(above)
An inexpensive crane for placing pipe in position

(at the left)
Unloading 24" cast iron pipe using skids

Much helpful data for the engineer and contractor is contained in the U. S. Cast Iron Pipe Hand book. May we send your copy now?

FIRST cost is usually the last cost with cast iron pipe . . . . And proper handling methods will not only insure a lasting job, but also materially reduce the first cost of installation.

The illustration above shows the simple equipment necessary for handling efficiently medium-sized cast iron pipe. The use of the inexpensive crane illustrated speeds up the work, reduces labor cost and helps to make a better finished job.

Practical experience indicates that the use of labor-saving devices may save as much as 40% of the cost of laying mains with hand labor alone. Skillful handling and good equipment on the job always pay.

United States Cast Iron Pipe and Foundry Company

General Offices:
Burlington, New Jersey

Philadelphia
Chicago
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New York

San Francisco
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Dallas
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Corrosion of Iron and Steel Water Pipes

Information on this subject is desired by the Committee recently appointed by the Association "to Collect and Correlate Information Concerning the Corrosion of Iron and Steel Pipes and Standpipes." Members are urged to send data relating to the characteristics of the metal, the soil, the water and the protective coatings and to the history and condition of such supply mains (not service pipes) to the undersigned for the use of the Committee.

CALEB MILLS SAVILLE, *Chairman.*
1026 Main Street, Hartford, Conn.

NICHOLAS ENGEL

JOHN FOX & CO.

CAST IRON

WATER & GAS PIPES

FLANGE PIPE

Special Castings, Fire Hydrants, Valves

General Foundry and Machine Work

WOOLWORTH BUILDING 233 BROADWAY

NEW YORK CITY

HIGHEST AWARD, GOLD MEDAL,
ST. LOUIS EXPOSITION, 1904

Over 100 Water Departments

use

LEAD-LINED IRON and TIN-LINED PIPES

for their service connections

MANUFACTURED BY

Lead Lined Iron Pipe Company

Wakefield ——— Mass.

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TRAILER
PUMP UNIT
— IS —
Light
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Efficient

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CAST IRON PIPE

Bell and Spigot Flanged Pipe
Special Castings
Flexible Joint Pipe Cylinders

Water Gas Sewers Culverts

Works, Phillipsburg, N. J.

LARGE STOCK ENABLES US TO MAKE QUICK SHIPMENTS

TRADE **"LEADITE"** MARK

Registered U. S. Pat. Office

Only 51 days between the decision to build an emergency water works plant - - *and the finished job!*

- - the speed with which Leadite jointing can be accomplished contributed to this remarkable feat.

THE line illustrated here is 26,000 ft. of 12" pipe with LEADITE joints.

Owing to the emergency which arose in the city for which the installation was made no trenching could be attempted.

The line lies throughout its entire length on the surface of the ground without any bracing except at the bends.

After completion the line was tested to 260 lbs. pump pressure.

It is now under constant pump working pressure of 230 lbs. For over 30 years now, LEADITE has demonstrated by test and experience that it is absolutely permanent and secure.

Leadite is self-caulking and is so simple to use that the method of using it can be taught to even the most inexperienced help in a very short time.

Added to its speed and ease of use — Leadite saves at least 75% on account of saving in material and labor.

Part of the 26,000 ft. installation, crossing an open field. Chas. E. Waddell & Co., Engineers.

Specify and use LEADITE —it saves at least 75%

Be sure it is LEADITE and accept no imitations : :

The pioneer self-caulking material for c. i. pipe. Tested and used for over 30 years.

THE LEADITE COMPANY Land Title Bldg. PHILADELPHIA, PA.

NO CAULKING

Chadwick-Boston Lead Co.

800 Albany St., Boston

Agents for

The Celebrated "ULCO"

LEAD WOOL

(Every Atom Pure Lead)

For calking pipe joints under the most difficult conditions.

For overhead joints, or in wet places where the use of molten lead is not only impracticable but dangerous — **LEAD WOOL** may be used to advantage.

It makes an absolutely tight joint which will withstand the highest pressure, yet be sufficiently elastic to allow considerable sagging or settling of the pipe without danger of a leak.

As compared with the poured joint, in this respect, the superiority of **LEAD WOOL** is apparent.

Manufacturers of

Lead Pipe, Tin Lined Lead Pipe, Pure Block-Tin Pipe, Solder, White Lead and Red Lead.

HIGHEST QUALITY SOFT BRANDS

PIG LEAD

TEN CENTS PER POUND PRICE TEN CENTS PER POUND PRICE TEN CENTS PER POUND TEN CENTS PER POUND

Join Your Water Mains

WITH

LEAD-HYDRO-TITE

TRADEMARK

AND CUT YOUR EXPENSES

50% FIRST COST

50% SMALLER BELL HOLES

75% HANDLING

100% CALKING

OUR PROPOSAL

That the prospective users purchase a trial lot of 1 to 5 bags, and that this be used under the direction and according to the instructions of our representative.

If, after a trial, the purchaser is not satisfied with the material, any surplus not used to be returned to the Hydraulic Development Company, and no charge to be made for any of the Hydro-Tite furnished.

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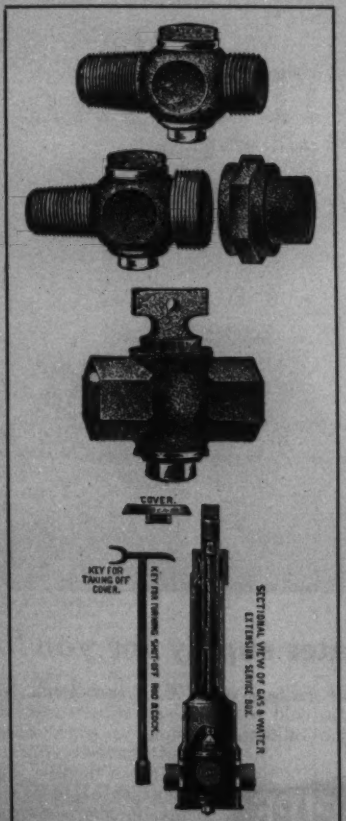

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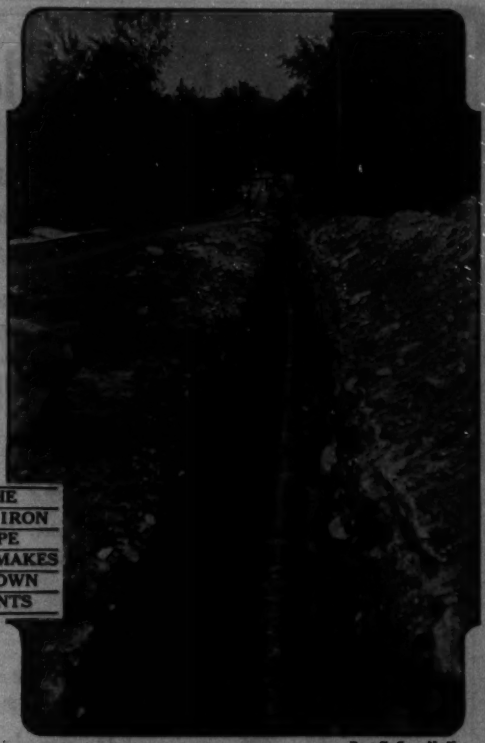

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Here's dependable water supply for you!

Dependable because it's 100% cast iron. No hot lead, no cold lead, no lead substitutes, no pouring, no calking. Nothing to work loose, nothing to deteriorate in these flexible, dependable joints—machined iron-to-iron *joints as tight as the wall of the pipe itself.*

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UNIVERSAL CAST IRON PIPE
No hell holes to dig. No joints to calk.
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Subsidiary of The Universal Pipe and Radiator Company
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Patent Automatic Cushioned Controlling Altitude Valves

We have enlightened many a water user in municipalities, in industrial plants and on railroads, as to the adaptability of these Golden-Anderson Valves, and as to their function of SAVING, and of eliminating troubles.

For automatically maintaining Uniform Stage of Water in Tank, Reservoir or Standpipes. Doing away with the annoyance of Freezing and Float Fixtures inside or outside of Tanks.

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Sizes to 24 in.

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"HOSTS OF REFERENCES"
Valves cushioned at all times by air and water
No water hammer or bursting mains

"Made with stop starter attachment for centrifugal pumps"

GOLDEN-ANDERSON
Pat. Automatic Cushioned Water Pressure Regulating Valves

1. Maintain a constant reduced pressure regardless of fluctuations on high pressure side.
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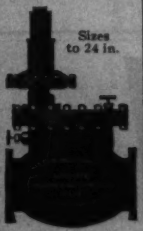
3. The best valve made for maintaining a constant low pressure where consumption is continuous.
4. Operates quickly or slowly as required — No attention necessary.
5. Positively no hammering or sticking.



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They carry a constant water level in feed water heaters by perfectly controlling the flow of makeup water.

Operated by protected enclosed copper float.

Cushioned by both air and water.

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4. No Metal-to-Metal Seats — No Water Hammer or Shock.
5. Cushioned by Water and Air.

Angle or Globe

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GOLDEN-ANDERSON
Patent Automatic Double Cushioned Check Valve

Sizes to 24 in. Angle or Globe

Automatically prevents reverse flow of pressure.

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Especially adapted for water works to prevent disastrous reverse flow of pressure due to pumps stopping.

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affords absolute protection from damage of any nature.

Perfect Lock

consists of one-piece phosphor bronze bolt engaging on an incline plane on cover to lock and likewise engages on a similar plane on lid to unlock. No rivets, bolts or screws, to rust, preventing operation.

The Only All Bronze Meter Box Lock.

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Manufacturers Waterworks Equipment

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SMITH High-Pressure Valves and Water Gates are the products of decades of designing and of experience. They have at least four points of superiority, as follows:

Simplicity of Construction
Non-Corrosive Working Parts
Operate in Any Position
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Send for Valve Booklet

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WATER WORKS SPECIALTIES & SUPPLIES
A.P.S. 1928

THE A.P. SMITH MFG. CO. *East Orange, N.J.*

RUST *destroys* Expensive Pavements

EVERY city, town and village boasts of its streets and sidewalks. Citizens point with pride to such improvements.

When water service pipes which carry the water into the homes are made of corrodible metal they soon become rust clogged. The result is that when the home owner turns on a faucet only a tiny trickle of reddish water drips. The rusting service pipe soon bursts. Streets and lawns must then be torn up so that necessary repairs can be made. It is a heavy financial burden to the taxpayer.

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Full information on the advantages of Copper or Brass pipe will be furnished you by this Association without cost or obligation.

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RESEARCH ASSOCIATION
25 Broadway, New York

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